The TREND IN ENGINEERING

at the University of Washington

In this issue:

HYPERSONIC FLOW ABOUT OGIVES FOR GASES IN CHEMICAL AND THERMODYNAMIC EQUILIBRIUM

THE APPLICATION OF TRANSISTORS TO A TRANSMISSION LINE RELAY

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THE ENGINEERING EXPERIMENT STATION of the University of Washington, which was established in December, 1917, performs a three-fold function:

1) It stimulates, promotes, and coordinates investigations and research in all fields of engineering.
2) It publishes results of significant research achievements.
3) It provides opportunities through Graduate Research Assistantships for engineering students to extend their professional education while pursuing a course of study leading to the M.S. or Ph.D. degree.

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WHAT ABOUT WOMEN ENGINEERS?

THE following appears in the 1959-1960 engineering college bulletin of a large southern state university:

> The field of engineering has been thought of almost exclusively as a man's domain. In the past few years, however, increasing numbers of women have been entering this field and are taking their places in the profession on an equal footing with men. Women who are interested in an engineering career and who have aptitudes in mathematics and science are invited to confer with the Dean of the College with reference to choosing engineering as a profession.

Here is one of a few small but hopeful signs that a much neglected source of engineering recruitment is receiving attention.

President Lee A. DuBridge pointed out several years ago that "we have almost completely failed in the physical sciences and engineering to make use of the talents and services of women," going on to remark that "Junior science fairs have discovered some very able girl scientists."[1]

In 1955, only 62 of 22,589 engineering graduates in the United States were women.[2] (This does not include the additional small number of women graduates in mathematics, physics, and chemistry who might become technical employees.) In the fall of 1958, 1,583 women were enrolled in engineering colleges for the first degree, 111 for the M.S. and 24 for the Ph.D. (or a total of 0.59% of the total engineering enrollment), but of 41,767 degrees in engineering conferred that year, only 133 were earned by women, or 0.32%,[3] a very slight increase over 1955. Although the number of employed women engineers jumped from less than 750 in 1940 to approximately 6,500 in 1950, the percentage of women employed as engineers in 1950 was only 1.24% of the total of employed engineers.[2] In the state of Washington the Boeing Airplane Company recruits women engineers and employs at present 94 women with engineering titles, 69 of whom perform actual engineering types of work. (These figures do not include engineering aides or "junior engineer" classifications.) The approximate number of employees with engineering titles (excluding aides and junior engineers) is 7500, showing that only about one per cent are women. Thus Boeing's recruiting efforts have resulted in a percentage less than the over-all U.S. average for 1950.

A very much higher percentage of women are being trained in science and technology in Soviet Russia, Poland, and Czechoslovakia, than in Europe, the U.S., or Canada; even Asia and South America, Australia, Thailand, Korea, have women engineers. Two women from Madagascar were studying aeronautical engineering at the time (1958) the United Nations Commission on the Status of Women conducted its survey on the participation of women in engineering, architecture, and law.[3] However, we must remember that there are few other careers open to bright ambitious women in the U.S.S.R. and its satellites,[1] and unusual inducements are offered to all scientists and technicians in those countries, equally to women and men. Great pressure is brought to bear on all students who show promising scientific aptitudes, so they may not be given much choice of profession. The U.N. survey also revealed that in 25% of the 40 countries concerned, women engineers meet with prejudice and opposition in seeking employment, and that "many countries have higher percentages of women among their engineers than the United States."[3]

While the population of the United States has doubled since 1900, the number of scientists and engineers has increased ten-fold,[1] indicating a possible long-term future trend of an even larger fraction of our working force directed toward scientific pursuits. The percentage of women so employed should surely at least remain constant. What is preventing women with unusual aptitudes in mathematics and science from considering engineering as a career? Are the age-old prejudices against women in any type of professional career still deeply ingrained in our culture? Here are some examples frequently encountered.

Prejudices and Facts

1. "Women are inherently less intelligent than men and are temperamentally unsuited for any professional career, being too emotional and imaginative."

The hoary dogma of woman's mental inferiority has long been exploded. As for temperament, the woman who is highly emotional is not likely to be interested in science or engineering. On the other hand, imagination, in women as well as in men, when combined with quick perception and rational judgment, is the very essence of creativity in any field.

2. "Women are physically unsuited to engineering work." This idea might have been valid a couple of generations ago when the kinship between engineers and skilled mechanics was very close. Today, apparently, the public, parents, and even some engineers have yet to realize that "most professional engineering jobs are accomplished at a desk and require no more exertion than wielding the compass and slide rule."[3]

3. "Turnover of women technical employees is greater than that of men. Women leave their jobs for marriage and child-bearing. Efficiency, therefore, demands that preference and promotion be given to men." Yet a management executive of "one of our larger corporations" stated that "any organization needs a host of young engineers, male and female. The latter, during those early years before their home duties call them away from industry, could perform a magnificent service. In later years they could return and again perform a service. Why don't they do it?"[4] And Leonard B. Landall of the Raytheon Manufacturing Company, which employs 32 women engineers, pointed out, at a conference on education of girls for careers in science and engineering, that "women are the nation's greatest untapped reserve of brainpower since they account for most of the two-thirds of the nation's top brain power that is not at present receiving college training."[5]

4. "Engineers resent women as co-professional workers and management fears that employee 'cohesiveness' is destroyed by introducing women engineers." This is a sweeping statement for which no substantial evidence appears ever to have been offered. Individual cases, probably among the older generation, can doubtless be found. On the other hand, numerous cases of dissatisfaction and enmity which threaten cohesiveness among all-male engineering groups can readily be cited.

5. "A married professional woman is likely to compete with her husband and thus upset the prescribed identity of the family social status."

In the first place, if a woman is temperamentally competitive, she will compete, whether on a professional basis or some other. In the second place, the "prescribed identity" is already being upset by the changing allover pattern

(Continued on page 32)

Johannes Kepler: Misfit, Dreamer, Genius

One of the strangest composite characters in the history of science was Johannes Kepler (1571-1630) whose Three Laws formed the base on which Newton, a century later, built the modern universe. His life was a series of contradictions and his philosophy a combination of the mystical and empirical.

Probably no other scientist has so frankly and completely confessed in writing his mistakes in calculations, misinterpretations of data, and wrong conclusions, only to bounce up each time with assurance that *now* he was on the right path. For that matter, probably no other great scientist ever *made* so many mistakes and misinterpretations, finally to emerge with findings whose tremendous significance he himself failed to recognize. Indeed, perhaps it took the genius of a Newton to detect and free the Laws from the mass of fantasy in which they were buried. One writer has said, "It is as if Einstein in his old age discussed his work without mentioning relativity. . . . Kepler, too, discovered his America, believing it was India."

His well-known Three Laws are briefly as follows: (1) each planet moves in an ellipse with the sun at one focus; (2) the radius vector of each planet passes over equal areas in equal intervals of time; and (3) the square of the period of revolution of a planet about the sun is proportional to the cube of the mean distance of the planet from the sun.

Kepler's unpromising childhood perhaps gives a clue to his almost schizophrenic personality. His rascally father early deserted the family; his mother was an evil-tongued superstitious woman who in later life narrowly escaped being burned as a witch. Johannes was a scrawny, unprepossessing youngster, half-blind as a result of smallpox. His early training was for the Church (Lutheran), and his religion and his dogged belief in the Copernican theory were his life's most stable convictions, although renouncing either or both would have led to his political and economic preferment.

Yet, in spite of his religious fervor, "he divorced astronomy from theology and married it to physics," consequently formulating the world's first modern scientific laws. And, in spite of his unswerving belief in the Copernican theory, he was able to work with Tycho Brahe who opposed it to his dying day, and, by combining Tycho's method of exact observation with mathematics (of which Tycho was "abysmally ignorant") he transferred ancient concepts from their traditional frame and looked at them, as it were, "through glasses of a different colour."

Various other contradictory influences gained ascendancy at different times of his life. His first reputation was won as Court Astrologer when he came close to predicting weather and events for the year based on the juxtaposition of the planets, sun and moon. Some of the "taint" of this pseudoscience possibly lingered even when, in later years, he was deriding it as a "dreadful superstition."

He could speak of the "soul" of the sun as governing the motion of its planets, yet he was the first to recognize that certain discrepancies, which had been observed for centuries, indicated non-circular planetary orbits. He describes the "heavenly motions" as being "but a continuous song for several voices," in his *Harmonia Mundi (Harmony of the Universe)*, yet that work contains the essence of his Third Law.

The first part of Kepler's early work, *Mysterium*, is medieval and mystical; the second part, empirical and scientific. He postulated two dynamic forces to explain the eccentricity of the planetary orbits: a notable creative "leap in the dark." His calculations, however, included several mistakes which would have failed to verify his theory except that toward the end of the chapter he committed several other mistakes in simple arithmetic which happened to cancel out the earlier ones.

In his *Astronomia Nova*, based on the observations of Tycho, "by three incorrect steps and their even more incorrect defense, he stumbled on the correct law" (the Second). Arthur Koestler describes it as "The most amazing sleepwalking performance in the history of science—except for the manner in which he found his First Law." Koestler also suggests that Kepler perhaps unconsciously adjusted his calculations and compensated for his errors by means of a built-in mental feedback—an idea worth consideration.

There is no question of Kepler's honesty. Had he been merely juggling figures to make them fit his theories, as did some of his contemporaries, he would not have devoted such patient years of toil to confirming his theories.

In the *Astronomia* is also a hint that Kepler narrowly missed a concept of universal gravity. He wrote:

> If two stones were placed anywhere in space near to each other, and outside the reach of force of a third cognate body, then they would come together, after the manner of magnetic bodies, at an intermediate point, each approaching the other in proportion to the other's mass.

However, he failed to develop this idea or apply it to his system. Again he wrote:

> The moving force . . . cannot be regarded as something which expands into the space between its source and the movable body, but as something which the movable body receives out of the space it occupies.

Koestler interprets this passage as "a description closer to the modern notion of the gravitational or electro-magnetic *field* than to the classic Newtonian concept of *force*."

A little known work of Kepler was the first piece of modern science fiction; that is, it was not based merely on fantasy. In the *Somnium (Dream)*, a tale he had worked on from his early twenties but which was not published until after his death, he describes a trip to the moon. Although the hero is propelled to the moon in four hours by the power of a demon summoned by a sorceress (the hero's mother), the description of his experiences enroute tallies with some very modern ideas. The hero was "dazed by opiates, beforehand," to make him oblivious to the "initial shock (of acceleration)." His limbs were "carefully protected so that they would not be torn from him" and "the

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ENTRANCE TO THE NEW MECHANICAL ENGINEERING BUILDING WHICH COVERS 100,000 SQUARE FEET.

Hypersonic Flow About Ogives for Gases in Chemical and Thermodynamic Equilibrium*

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The supersonic flow of a gas about bodies of revolution has important applications to the analysis of the flow about airplane fuselages and the flow about missiles. A number of methods have been developed[1] to determine, with varying degrees of accuracy and lengths of calculation time, the pressure distributions about pointed-nose bodies of revolution at zero incidence for thermally perfect gases. One of the most accurate of these methods at high supersonic Mach numbers is the method of "conical shock-expansions."[2] However, at hypersonic speeds the assumption of a thermally perfect gas causes an increasing amount of error with increasing Mach number. Much information has yet to be obtained about the flow of thermally imperfect gases at these high Mach numbers.

Recently the static conditions for argon-free air in chemical equilibrium have been determined by an analytical procedure.[3] A considerable range of these results has been used as the basis for the preparation of a Mollier diagram.[4]

More recently, the results of Hilsenrath and Beckett and the Mollier diagram by Feldman have been used by Mary Romig to determine the change in conditions of argon-free air in chemical equilibrium upon passage through a conical compression wave for a significant range of wave angles and free-stream air conditions.[5]

The present paper discusses the irrotational, isentropic, adiabatic flow of argon-free air in chemical equilibrium about pointed-nose bodies of revolution at zero incidence.[6] It considers flows represented by an initial conical compression wave followed by a region of continuous expansion. The free-stream flow conditions are assumed to be known. (The changes in flow conditions through the conical compression wave have already been determined.[5]) The equations upon which Eggers and Savin based their method of "conical shock-expansion" for supersonic flow of thermally perfect gases about ogives are re-evaluated and modified to represent the flow of thermally imperfect gases. A modified differential equation is obtained for the expansion region of flow. This equation does not depend on the assumption of a thermally perfect gas, but it does assume that the flow is irrotational.

The method combines (1) the use of the Mollier diagram[4] (or gas tables[3]), (2) the Romig theory for the change in flow conditions through a conical compression wave, and (3) the modified theory for expansion of thermally imperfect gases as described above. By this combination and by the assumption of constant total enthalpy, a graphical-numerical method is established for determining the properties of gases in thermodynamic and chemical equilibrium flowing at hypersonic speed at the surface of an ogive at zero incidence. This method is used to determine the flow conditions (such as static pressure, temperature, and density) on the surface of a representative ogive for a range of free-stream Mach numbers and pressures at one free-stream static temperature.

Differential Equation for the Expansion Region

The hypersonic flow over an ogive consists of an initial compression shock wave followed by a region of more-or-less continuous expansion. For the flow at the surface of the ogive, the conditions through the initial compression wave are analyzed by use of theories for bow shock waves for cones. Following is the development of a differential equation representing the flow at the surface in the expansion region for conditions of either a thermally perfect or thermally imperfect gas.

The derivation of this equation makes use of the fundamental equations for a fluid in motion. It arrives at a form of the compatibility equations for characteristic lines. Combination and simplification of these compatibility equations follow closely the method established by Eggers and Savin of the NACA in their derivation of the comparable differential equation representing flow at high supersonic speeds of thermally perfect gases in the expansion regions about bodies of revolution.[2]

* Condensed and arranged from Mr. Ribe's thesis for the degree of M.S. in Aeronautical Engineering, 1958, written under the supervision of Professor R. E. Street.

NOMENCLATURE

a = speed of sound at constant entropy (ft/sec)
A = area of cross section of ogive (ft²)
c_1 = distance along a left-running characteristic line
c_4 = distance along a right-running characteristic line
C_P = static-pressure coefficient
h = enthalpy (ft²/sec²)
F = symbol representing $V^2/2$ (ft²/sec²)
M = Mach number
P = local static pressure
r = radial coordinate (same as y)
R = universal gas constant for thermally perfect gases
s = distance along a streamline
S = entropy of a gas
T = absolute temperature
u = velocity component in the x direction for a rectangular coordinate system and in the radial direction for a polar coordinate system (ft/sec)
v = velocity component in the y direction for a rectangular coordinate system and perpendicular to the radial direction for a polar coordinate system (ft/sec)
V = total velocity composed of the components u and v (ft/sec)
x = distance along an ogive axis from the apex
y = local radius of an ogive section
β = angle between a characteristic line and a streamline at their point of intersection
δ = local angle of inclination of the flow. At the surface of a body of revolution δ becomes equal to the local angle of the surface with respect to the axis of symmetry
δ_C = semi-angle of a cone or the semi-angle of an ogive at the apex
γ = ratio of the specific heat of a gas under constant pressure conditions to the specific heat under constant volume conditions
λ', λ'' = local tangent slopes, respectively, of the left- and right-running characteristic lines
ν = angle of expansion; always expressed as the change in expansion angle from some initial value ($\nu - \nu_{\text{init.}}$)
ρ = local static air density (slugs/ft³)
θ_V = semi-angle of a cone in the notation of Ref. 5
θ_W = angle between the compression bow wave and axis of symmetry of a cone at zero angle of incidence in the notation of Ref. 5

Subscripts

1 = free-stream conditions
init(ial) = conditions on the surface of a body of revolution just downstream of the compression bow wave
T = total or stagnation conditions

By use of the Euler equation of momentum,

$$-dp=\rho d\left(\frac{V^2}{2}\right)=\frac{\rho}{2}\,d(u^2+v^2)\,, \tag{1}$$

and the equation for the speed of sound at constant entropy,

$$a^2=\left(\frac{\partial p}{\partial \rho}\right)_S\,, \tag{2}$$

we can obtain the equations,

$$u\frac{\partial u}{\partial x}+v\frac{\partial v}{\partial x}+\frac{a^2}{\rho}\frac{\partial \rho}{\partial x}=0\,, \tag{3}$$

$$u\frac{\partial u}{\partial y}+v\frac{\partial v}{\partial y}+\frac{a^2}{\rho}\frac{\partial \rho}{\partial y}=0\,, \tag{4}$$

where u and v, are the velocity components with respect to a rectangular coordinate system, x, y, in a meridian plane of a body of revolution at zero incidence (Fig. 1). The equation of mass-flow continuity for flow in a meridian plane is

$$\rho\left(\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}\right)+u\frac{\partial \rho}{\partial x}+v\frac{\partial \rho}{\partial y}+\frac{\rho v}{y}=0\,. \tag{5}$$

By substitution of $\partial\rho/\partial x$ and $\partial\rho/\partial y$ from Eqs. 3 and 4, we obtain,

$$\rho\left(\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}\right)-\frac{\rho}{a^2}\left(u^2\frac{\partial u}{\partial x}+uv\frac{\partial u}{\partial y}+uv\frac{\partial v}{\partial x}+v^2\frac{\partial v}{\partial y}\right)=-\frac{\rho v}{y}\,. \tag{6}$$

Now, for irrotational flow,

$$\frac{\partial u}{\partial y}-\frac{\partial v}{\partial x}=0\,. \tag{7}$$

The two relationships exist,

$$du=\frac{\partial u}{\partial x}dx+\frac{\partial u}{\partial y}dy\,, \tag{8}$$

$$dv=\frac{\partial v}{\partial x}dx+\frac{\partial v}{\partial y}dy\,. \tag{9}$$

Equations, 6, 7, 8, and 9 can be solved simultaneously for the variables $\partial u/\partial x$, $\partial u/\partial y$, $\partial v/\partial x$, and $\partial v/\partial y$.

The augmented matrix for these four linear equations is[7]

$$\begin{array}{ccccc} \frac{\partial u}{\partial x} & \frac{\partial u}{\partial y} & \frac{\partial v}{\partial x} & \frac{\partial v}{\partial y} & \\ \rho\left(1-\frac{u^2}{a^2}\right) & -\frac{\rho}{a^2}uv & -\frac{\rho}{a^2}uv & \rho\left(1-\frac{v^2}{a^2}\right) & -\frac{\rho v}{y} \\ 0 & 1 & -1 & 0 & 0 \\ dx & dy & 0 & 0 & du \\ 0 & 0 & dx & dy & dv \end{array} \tag{10}$$

Since characteristics are curves or surfaces across which the derivatives $\partial u/\partial x$, $\partial u/\partial y$, $\partial v/\partial x$, and $\partial v/\partial y$ can be discontinuous or indeterminate, Cramer's rule states that under such conditions both numerator and denominator determinants must be equal to zero. By solving for $\partial u/\partial x$ we obtain two equations which are necessary and sufficient for $\partial u/\partial x$ to be indeterminate:

denominator:

$$(a^2-u^2)\,dy^2+2\,uv\,dx\,dy+(a^2-v^2)\,dx^2=0\,, \tag{11}$$

numerator:

$$(a^2-u^2)\,du\,dy+(a^2-v^2)\,dv\,dx+a^2\frac{v}{y}dx\,dy=0\,. \tag{12}$$

The matrix (10) can, at most, be of rank three. Therefore, $\partial u/\partial y$, $\partial v/\partial x$, and $\partial v/\partial y$ will also be indeterminate along the characteristic line represented by Eqs. 11 and 12. The curves represented by these equations are intercepts of characteristic surfaces with a meridian (x, y) plane.

Equation 11 is a quadratic in dy/dx. The two solutions are:

$$\frac{dy}{dx}=\lambda', \tag{13}$$

and

$$\frac{dy}{dx}=\lambda'', \tag{14}$$

where

$$\lambda'=\frac{uv+a\sqrt{u^2+v^2-a^2}}{u^2-a^2}, \tag{15}$$

$$\lambda''=\frac{uv-a\sqrt{u^2+v^2-a^2}}{u^2-a^2}, \tag{16}$$

with the condition that $u^2+v^2\geq a^2$ for real characteristics. It has been established that these characteristic lines are Mach lines; therefore,

$$\lambda'=\tan(\delta+\beta), \tag{17}$$

$$\lambda''=\tan(\delta-\beta), \tag{18}$$

for left- and right-running characteristics, respectively. Combination of Eqs. 12 and 13 results in

$$(a^2-u^2)\,\lambda'\,du+(a^2-v^2)\,dv+a^2\frac{v}{y}dy=0. \tag{19}$$

Combination of Eqs. 12 and 14 results in

$$(a^2-u^2)\,\lambda''\,du+(a^2-v^2)\,dv+a^2\frac{v}{y}dy=0. \tag{20}$$

Equations 19 and 20 are known as the compatibility equations for the characteristics.

By the procedure of Ref. 7, Eqs. 19 and 20 may be changed, respectively, to the equations of compatibility in the modified form,

$$d\delta-\cot\beta\frac{dV}{V}+\frac{\sin\delta\sin\beta}{y}dc_1=0, \tag{21}$$

$$d\delta+\cot\beta\frac{dV}{V}-\frac{\sin\delta\sin\beta}{y}dc_2=0, \tag{22}$$

where

$$dc_1=\frac{dy}{\sin(\delta+\beta)}\,;\ dc_2=\frac{dy}{\sin(\delta-\beta)}\,;\text{ and } V^2=u^2+v^2.$$

Reference 7 proves that the last term in each of these equations approaches a finite expression as y approaches zero. Equations 21 and 22 are similar to Eqs. 31 and 32 of Ref. 2 but were derived without use of the energy equation or without the assumption of a constant ratio of specific heats, γ. Equations 21 and 22 are rearranged and combined with identities based on the flow geometry to obtain a single equation:

$$\frac{\cos^2\beta}{\sin\beta}\frac{dV}{V}=\cos\beta\,d\delta-\left(\frac{\partial\delta}{\partial c_1}+\frac{\sin\delta\sin\beta}{y}\right)ds. \tag{23}$$

Following the procedure of Ref. 2, the regions near the vertex and downstream of the vertex of the body of revolution are considered separately. By using the geometry of hypersonic flow over bodies with near-conical noses, Eq. 23 is simplified,[6] for both regions, to the following equation:*

$$\frac{\cos\beta}{\sin\beta}\frac{dV}{V}=-d\delta=d\nu. \tag{24}$$

This equation is independent of the ratio of specific heats, γ, the energy equation in integrated form, and the equation of state, being dependent on the momentum equation, constant entropy, the mass-continuity equation, and the geometry of the flow. It is, therefore, suitable for study of the expansion flow of thermally imperfect gases at hypersonic speeds about bodies of revolution. Equation 24 can be shown[6] to be equivalent, by assumption of constant total enthalpy, to the expression,

$$\nu-\nu_{\text{init.}}=\frac{1}{2}\int_{F_{\text{init.}}}^{F}\left(\frac{2F}{a^2}-1\right)^{\frac{1}{2}}\frac{dF}{F}, \tag{25}$$

where $F=V^2/2$. This is Eq. 21 of Ref. 4. Equation 25 is the differential equation for two-dimensional Prandtl-Meyer expansion of thermally imperfect or perfect gases in chemical equilibrium for constant total enthalpy. In the next section this equation will be used for determining the flow properties about an example ogive.

Flow About a Sine Ogive

Several recent analyses have provided some necessary information for determination of the inviscid, irrotational, adiabatic flow of argon-free air in chemical equilibrium at high Mach numbers about bodies of revolution of arbitrary contour at zero incidence angle. One of these analyses was an accurate determination by Hilsenrath and Beckett[3] of the static properties of argon-free air at temperatures to 15,000° K and the preparation by Avco Research Laboratory of a Mollier diagram for these properties.[4] The second significant analysis was the determination of the flow properties of argon-free air in chemical equilibrium flowing past a cone at

*Sometimes used for calculation of a supersonic Prandtl-Meyer expansion.

hypersonic speeds. These results were obtained by Mary Romig of the Convair Scientific Research Laboratory.[5] Use is now made of both Refs. 4 and 5 in determining the flow over the example ogive ($y=r=\sin x$).

Flow over the ogives under consideration is typified by an initial compression shock wave followed by a region of expansion, as shown in Fig. 1.

In the region approaching the apex the flow is very close to conical. The theory for flow over cones[5] is

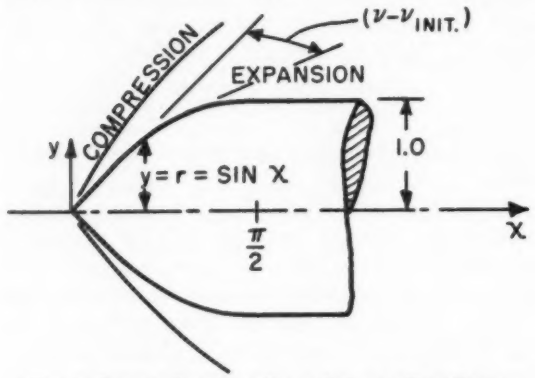

FIG. 1. SKETCH SHOWING FLOW ABOUT A SINE-OGIVE

used to determine the initial conditions of entropy, static density, static pressure, static temperature, air speed, and the speed of sound on the surface just downstream of the compression wave. From the entropy and any one of these other properties, except the air speed, the enthalpy at the apex (called here the initial enthalpy) can be determined by reference to the Mollier diagram of Ref. 4. Since the entropy is considered constant at the surface downstream of the compression wave, the flow conditions with respect to the enthalpy may be obtained from the Mollier diagram. The air speed is related to the enthalpy by

$$h_T=h+\frac{V^2}{2}. \tag{26}$$

where h_T is the total enthalpy (assumed to be constant). Flow conditions in the expansion region can then be determined by use of the equation for two-dimensional Prandtl-Meyer flow:

$$\nu-\nu_{\text{init.}}=\int_{F_{\text{init.}}}^{F}\left(\frac{1}{2a^2F}-\frac{1}{4F^2}\right)^{\frac{1}{2}}dF, \tag{25}$$

where F is related to the enthalpy by Eq. 26. Since

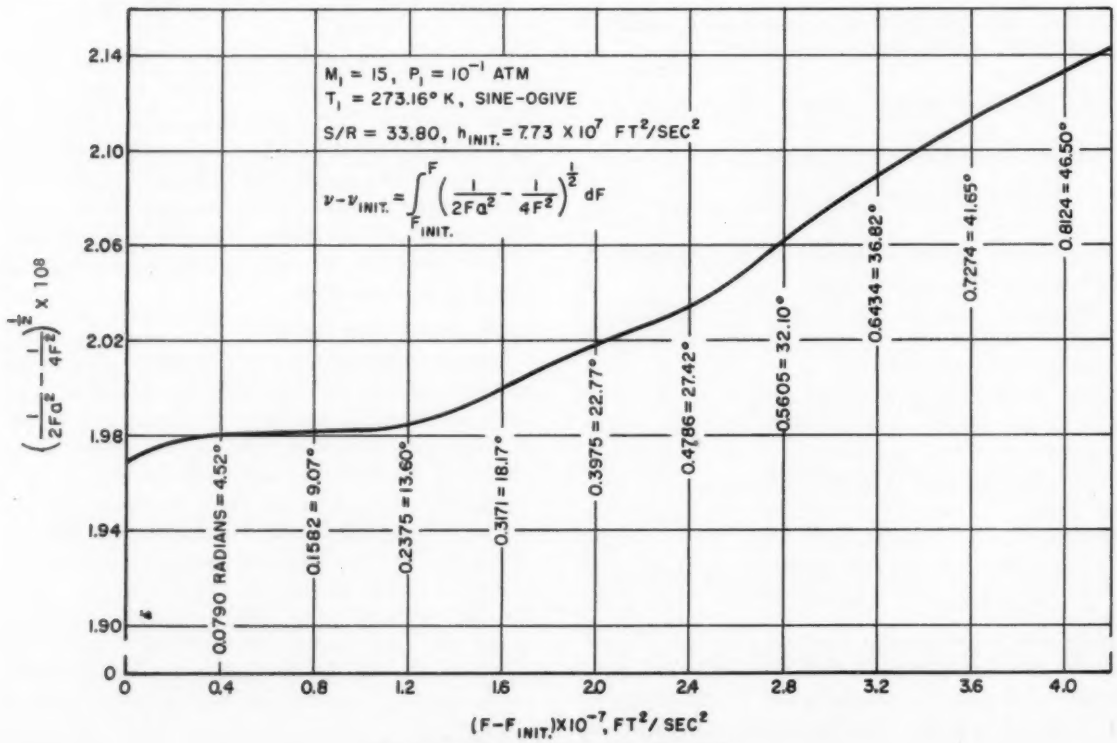

FIG. 2. EXPANSION-ANGLE CALCULATION

the flow conditions have been determined with respect to the enthalpy, if the expansion angle also is calculated with respect to the enthalpy, the flow conditions will then be known with respect to the expansion angle, $(\nu-\nu_{init.})$, for specific initial conditions of entropy and total enthalpy. The expansion angle is assumed to be a known function of the geometry of the ogive.

The sine-ogive was used as an illustrative example for several reasons. Its contour, being near-conical in the region of the apex and for some distance downstream, fits the assumptions of the theory for the expansion region. The ordinates (or radii) are known, being $y=\sin x$, with x in radians, $(0\leq x\leq \pi/2)$. This ogive has a fineness ratio of $\pi/4$ and tangent slope of 45° at the apex. A 45° expansion downstream of the apex results in flow parallel to the axis of symmetry.

Flow conditions over the ogive were calculated for free-stream Mach numbers, M_1, of 10, 15, 20, and 25 at free-stream static pressures, P_1, of 10^{-1} and 10^{-4} atmosphere. This is a combined graphical and numerical procedure, and is outlined as follows:

1. The hypersonic similarity parameter, $M_1 \sin \theta_V$, for a 45° semi-angle cone was calculated for each of the free-stream Mach numbers.

TABLE I

TYPICAL EXPANSION-ANGLE CALCULATION

$M_1=15$; $P_1=10^{-1}$ atm

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
$h\times10^{-7}$ (fps)^2	$a^2\times10^{-7}$ (fps)^2	$\Delta h\times10^{-7}$ (fps)^2	$a^2\times10^{-7}$	$2F\times10^{-7}$	$2F\times10^{-7}$	$(2F)^2\times10^{-14}$	$(2Fa^2)\times10^{-14}$					(12)×ΔF (rad.)	$\Delta\nu$ (deg.)	$\nu-\nu_{init.}$ (deg.)
			Ave. of (2)	$V^2\times10^{-7}$	Ave. of (5)	$(6)^2$	(4)×(6)	$\frac{100}{(8)}\times10^{16}$	$\frac{100}{(7)}\times10^{16}$	(9) − (10) $\times10^{16}$	(11)$^{\frac{1}{2}}$ $\times10^8$	(12) ×(−3)	57.3 ×(13)	Σ(14)
7.73	1.742			12.80										0
		−0.13	1.726		12.93	167.3	22.30	4.48	0.597	3.89	1.972	0.0256	1.468	
7.60	1.710			13.06										1.468
		−0.20	1.687		13.26	175.8	22.35	4.48	0.569	3.91	1.978	0.0396	2.267	
7.40	1.665			13.46										3.735
5.20	1.240			17.86										28.931
		−0.20	1.220		18.06	326.0	22.02	4.54	0.307	4.23	2.057	0.0411	2.353	
5.00	1.200			18.26										31.284
		−0.20	1.185		18.46	340.3	21.85	4.58	0.294	4.29	2.070	0.0414	2.372	
4.80	1.170			18.66										33.656
		−0.20	1.155		18.86	355.6	21.80	4.59	0.282	4.31	2.078	0.0415	2.378	
4.60	1.140			19.06										36.034
		−0.40	1.110		19.46	378.4	21.60	4.63	0.264	4.37	2.115	0.0846	4.848	
4.20	1.080			19.86										40.882
		−0.40	1.048		20.26	411.0	21.25	4.71	0.244	4.47	2.115	0.0846	4.846	
3.80	1.016			20.66										45.728
		−0.40	0.983		21.06	445.0	20.70	4.84	0.225	4.61	2.145	0.0859	4.920	
3.40	0.950			21.46										50.648

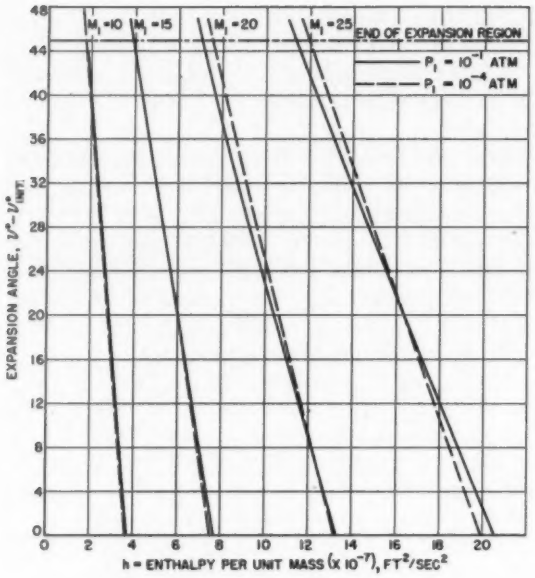
M_1 = 10
M_1 = 15
M_1 = 20
M_1 = 25
END OF EXPANSION REGION
$P_1 = 10^{-1}$ ATM
$P_1 = 10^{-4}$ ATM
EXPANSION ANGLE, $\nu^\circ - \nu^\circ_{INIT.}$
h = ENTHALPY PER UNIT MASS (x 10^{-7}), FT^2/SEC^2

FIG. 3. EXPANSION-ANGLE VARIATION WITH ENTHALPY FOR THE SINE-OGIVE

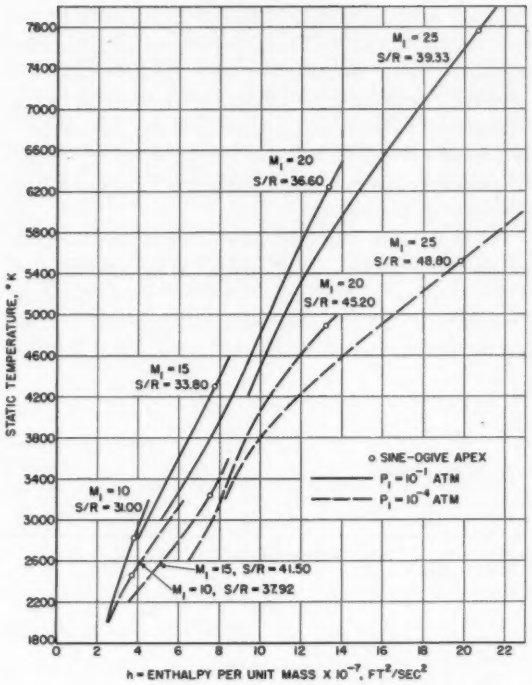

FIG. 4. STATIC TEMPERATURE AT CONSTANT ENTROPY FOR THE SINE-OGIVE

2. With this hypersonic similarity parameter, the conical shock-wave parameter, $M_1 \sin \theta_W$, for each Mach number was determined from Fig. 6 of Ref. 5.
3. The dimensionless entropy, S/R, at the vertex behind the conical compression wave was determined for the specific free-stream flow conditions from Fig. 2 of Ref. 5. The dimensionless entropy is related to the enthalpy and to the air conditions by the Mollier diagram.
4. The static-pressure ratio, static-temperature ratio, static-density ratio, and air speed at the apex downstream of the compression wave were obtained from Figs. 7, 8, 9, and 16 of Ref. 5.
5. Using the dimensionless entropy and either the pressure ratio or static temperature from step (4), the enthalpy at the apex downstream of the compression wave (initial enthalpy) was obtained from the Mollier diagram.
6. The expansion angle of the flow downstream of the vertex ($\nu - \nu_{init.}$) was calculated, using Eq. 25. Equation 25 can be integrated numerically as in Table I or graphically as in Fig. 2. The speed of sound, a, was determined from an adaptation of Fig. 4 of Ref. 5 for values of entropy previously determined and for a decreasing sequence of values of enthalpy less than the initial enthalpy.

The quantity $\left(\frac{1}{2Fa^2} - \frac{1}{4F^2}\right)^{\frac{1}{2}}$ was calculated for values of F corresponding to the assumed values of h and for the corresponding speed of sound, a. The results were plotted versus $F - F_{init.}$ for each flight condition (Fig. 2). The cumulative area under the curve of Fig. 2 to the right of the vertical axis is equal to the expansion angle in radians (Eq. 25). The area can also be determined numerically, as shown in Table I. The enthalpy, h, is related to F by Eq. 26; thus the expansion angle can be determined with respect to the enthalpy. Results of this calculation are shown in Fig. 3. Temperature, pressure ratio, and density ratio may be obtained from the Mollier diagram for the known entropy by interpolation to the correct assumed values of enthalpy. Or, these conditions may be obtained from plots based on the Mollier diagram (Figs. 4 and 5). With the flow expansion angle and gas conditions both given as functions of the enthalpy, the gas conditions are known as functions of the expansion angle. Static-temperature variation with expansion angle for the example conditions is presented in Fig. 6.

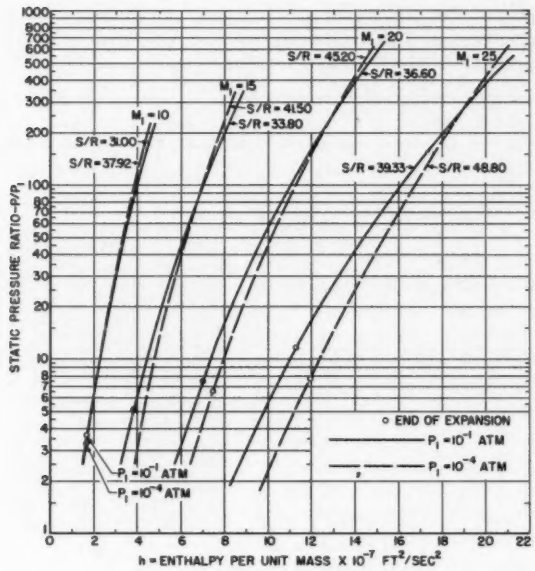

FIG. 5. LOCAL STATIC-PRESSURE RATIO AT CONSTANT ENTROPY FOR THE SINE-OGIVE

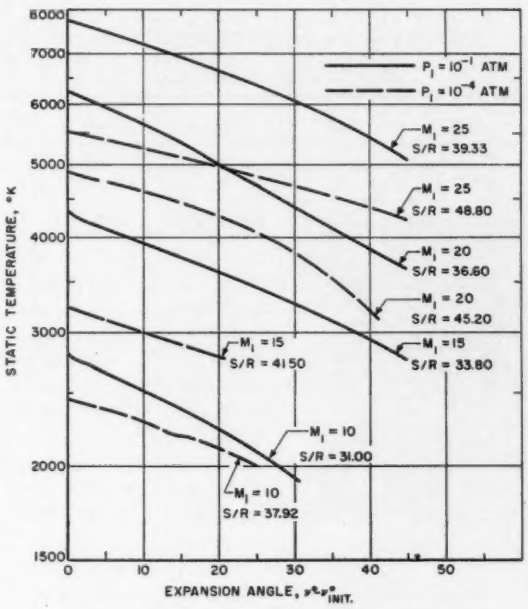

FIG. 6. STATIC-TEMPERATURE VARIATION WITH EXPANSION ANGLE FOR THE SINE-OGIVE

7. The pressure coefficient (C_P) was calculated from the pressure-ratio results of step (6) and numerically integrated over the ogive (Table II) to obtain the coefficient of pressure drag. The pressure-drag coefficient was calculated as presented in Fig. 7.

Results and Conclusions

The method developed in this paper, in conjunction with the analyses of Refs. 3, 4, and 5, should provide useful information about the hypersonic flow of thermally imperfect gases about bodies of revolution.

The over-expansion usually found in supersonic flow of thermally *perfect* gases about cones and ogives appears to be absent in the flows of thermally *imperfect* gases about the sine-ogive just considered. For thermally *perfect* gases the initial three-dimensional compression wave and the succeeding, predominantly two-dimensional expansion create negative pressure coefficients for a region just downstream of the ogive. Figure 5 indicates that this effect is absent for the conditions studied.

Pressure drag for the sine-ogive, calculated by the Newtonian method ($C_P = 2 \sin 2\delta$) for comparison purposes, is also presented in Fig. 7. Ehret gives a comparison of the accuracy of approximate methods for determination of pressure-drag coefficient at

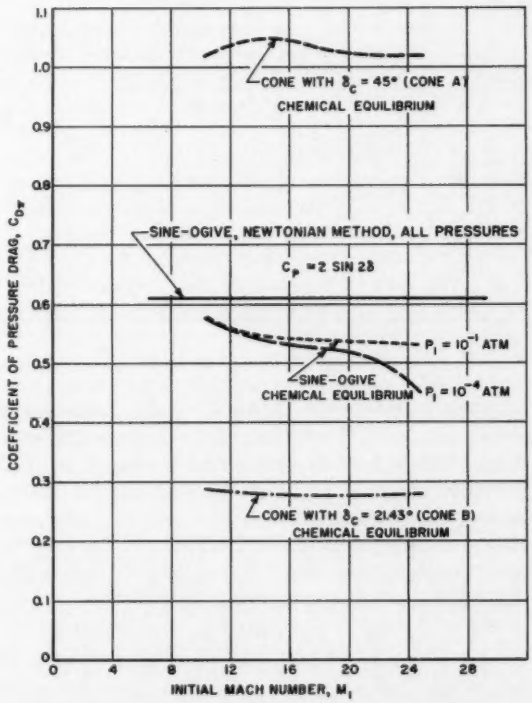
COEFFICIENT OF PRESSURE DRAG, C_{D_P}
INITIAL MACH NUMBER, M$_1$
CONE WITH δ_c = 45° (CONE A)
CHEMICAL EQUILIBRIUM
SINE-OGIVE, NEWTONIAN METHOD, ALL PRESSURES
$C_p = 2 \sin 2\delta$
P$_1$ = 10^{-1} ATM
SINE-OGIVE
CHEMICAL EQUILIBRIUM
P$_1$ = 10^{-4} ATM
CONE WITH δ_c = 21.43° (CONE B)
CHEMICAL EQUILIBRIUM

FIG. 7. COMPARISON OF COEFFICIENTS OF PRESSURE DRAGS ACCORDING TO VARIOUS TEHORIES

TABLE II

CALCULATION OF STATIC TEMPERATURE AND PRESSURE AND PRESSURE DRAG COEFFICIENT FOR THE SINE OGIVE
$M_1=15$; $P_1=10^{-1}$ atm

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
x (rad.)	ΔA	$\nu-\nu_{init.}$ (deg.)	$h\times10^{-7}$ (ft^2/sec^2)	T (°K)	P/P_1	C_P	$C_{P_{ave.}}$	$C_{P_{ave.}}\Delta A$
Axial Station	Cross Section Area Change	Expansion Angle	Enthalpy (Fig. 3)	Static Temp (Fig. 4)	Stat. Press. Ratio (Fig. 5)	$C_P=\frac{(P/P_1)-1}{0.7M_1^2}$		(8)×(2)
0		0	7.73	4295	164	1.035		
	0.0313						1.026	0.0321
0.10		0.17	7.71	4280	161	1.017		
	0.0926						1.010	0.0935
0.20		0.58	7.67	4260	159	1.003		
	0.1502						0.972	0.1461
	0.1885						0.148	0.0279
1.30		30.31	5.10	3265	19.6	0.118		
	0.1347						0.096	0.0129
1.40		35.35	4.67	3090	12.8	0.075		
	0.0751						0.059	0.0044
1.50		40.96	4.20	2905	7.7	0.043		
	0.0160						0.035	0.0006
1.57		45.00	3.86	2760	5.3	0.027		
							$\Sigma C_P\Delta A=$	1.7054

$$C_{D_T}=\frac{\Sigma C_P\Delta A}{A}=\frac{1.7054}{3.1416}=0.542$$

supersonic speeds for thermally perfect gases, and shows that the Newtonian method gives pressure-drag coefficient results *lower* than the exact method (of characteristics) and *lower* than for the thermally-perfect gas counterpart[2] of the method presented herein. Figure 7 shows the Newtonian method to give *higher* results than the results for thermally imperfect air presented in this report.

For comparison purposes, the pressure-drag coefficients based on argon-free air in chemical equilibrium for flow over two cones are also shown in Fig. 7. Cone A ($\delta_c=45°$) has the same semi-angle as the apex of the sine-ogive. Cone B ($\delta_c=21.43°$) has the same fineness ratio as the sine-ogive, but has less than half the semi-angle at the apex. These cone-drag calculations are based on the Romig method.[5]

The theory for thermally perfect gases predicts that both the static temperature on the surface of the ogive and the pressure-drag coefficient for the ogive are independent of the free-stream static pressure. However, according to the present theory for thermally imperfect gases, Figs. 3, 4, and 7 show a substantial effect of free-stream static-pressure change on both the static temperature on the ogive and the pressure-drag coefficient for the ogive.

(Continued on page 15)

STUDIES OF THE PHYSICS OF ENGINE KNOCK*

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Engine knock has always been an obstacle to the improvement of the efficiency and the power output of gasoline engines. The automobile and petroleum industries have done a considerable amount of successful research on the chemical process of knock, resulting in marked improvements in the development of more efficient fuels, improved gasoline refining processes, and use of antiknock additives. This success with the studies of the chemistry of knock, however, has drawn attention away from the physical process of knock and hence only limited work has been done on that aspect of the problem. It is believed that still further improvements in engine efficiency and power output can be realized through studies of the physical process of knock.

The Process and Theories of Knock

In the normal operation of the spark-ignition engine the flame is initiated by the spark plug and moves uniformly across the combustion chamber, compressing the unburned fuel-air mixture (end-gas) in front of it. The advancing flame front increases the end-gas temperature and pressure, which are dependent on the engine operating condition and the type of fuel used. If they are below a certain critical value, the flame front will move forward until all of the fuel is consumed. If, however, the temperature and pressure of the end-gas are sufficiently high, a cool flame is initiated and leads to knock.

Among a number of different theories proposed to explain the process of knock, the autoignition theory and the detonation wave theory[1] are the most widely accepted, but no single theory of knock has yet received general acceptance.

According to the detonation wave theory, the cool flame reaction in the engine accelerates and sets up a shock wave which, if it is severe enough, becomes a detonation wave and thus produces knock. The autoignition theory, however, assumes that the cool flame reaction in the end-gas accelerates very rapidly and abruptly completes the burning of the end-gas, resulting in violent vibrations throughout the entire contents of the combustion chamber and causing knock.

Rahim Lavi

In order to understand the physical process of knock, it is necessary to have a clear knowledge of the origin of the shock wave and its relation to detonation.

Shock Wave and Detonation

The origin of shock is most easily demonstrated by a simple experiment in which a long glass tube is used, with one end closed by a piston and the other end open. The tube contains a mixture of fuel and air or any other gas. Originally the piston is at rest and the gas inside of the tube has no velocity. The acceleration of the piston will produce a compression wave in the gas that travels at approximately the speed of sound. The gas between the compression wave and the piston is moving at a velocity equal to the velocity of the piston. Further acceleration of the piston will produce a second compression wave, traveling slightly faster than the first compression wave, since it is moving in a medium that has already been heated by the first compression wave. The velocity of the second compression wave is therefore greater than the velocity of the first; hence it tends to overtake the first compression wave. If the velocity of the piston is increased by another increment, a third pressure wave will arise and will travel faster than the preceding waves for the same reason. By accelerating the piston a number of times, several pressure waves can be produced, each moving faster than the preceding one. As soon as the following waves have overtaken and merged with the first wave, a shock wave is formed that moves with a velocity greater than the velocity of sound, relative to the uncompressed gas.

The occurrence of the shock wave in the tube causes a pressure rise which results in an increase in the temperature of the gas mixture. The gas mixture,

* Condensed and arranged from Mr. Lavi's thesis for the degree of M.S. in Mechanical Engineering (1958), under the supervision of Professor Firey.

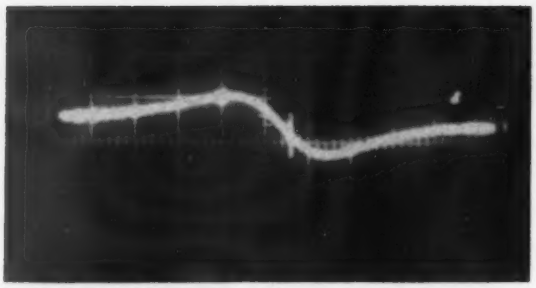

FIG. 1. OSCILLOGRAM SHOWING RATE OF PRESSURE CHANGE FOR AIR COMPRESSION ONLY

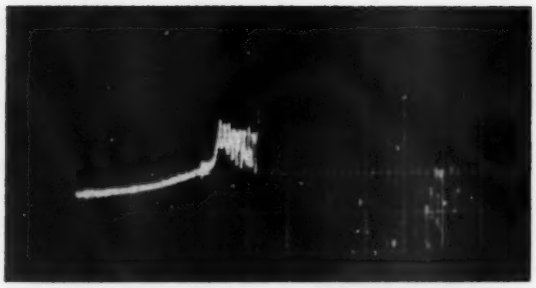

FIG. 2. OSCILLOGRAM SHOWING RATE OF PRESSURE CHANGE FOR COMPRESSION OF NORMAL HEPTANE PLUS 6 ML TETRAETHYL LEAD

Note shock wave formation by cool flame reaction, followed by detonation.

having high temperature and pressure, may undergo a chemical reaction and thus tend to expand. Such expansion of the reacting gas mixture is similar to the acceleration of the piston and consequently can lead to the formation of shock waves. These shock waves add to the shock waves already formed by the acceleration of the piston and thus push the temperature and pressure of the gas mixture to much higher values. This in turn causes the chemical reaction to take place more violently and sets up a chain process. The reaction energy of the mixture thus maintains the shock wave, which becomes a detonation wave.

This paper primarily deals with the detonation wave theory of knock and attempts to show that preflame reactions generate shock waves which lead to detonation and cause knock. From previous studies[2] it has been shown that the presence of impact pressures in the combustion chamber of an engine will indicate the presence of shock or detonation waves.

Impact Pressure Gage

The presence and intensity of the shock waves can be detected by means of an impact pressure gage consisting of a test beam inserted in the combustion chamber of a knocking engine. The impact pressure gage is located on the engine in such a manner that the static pressure on both faces of the test beam are equal, and only directional impact pressures can cause the beam to deflect or vibrate.

Two types of impact pressure gage, the "strain-gage detector" and "contactor gage" were used in these studies. In the strain-gage detector, the deflection of the test beam was measured by means of two high-temperature strain gages located on both faces of the cantilever test beam. Further protection was provided for the strain gages by covering the beam with a brass shield which was silver-soldered to the test beam to provide a gas-tight seal. A battery-powered DC Wheatstone bridge in connection with a cathode-ray oscilloscope was used to measure the electrical signals of the strain gages. The two strain gages were used in the adjacent legs of the bridge to double the output of the bridge and also to take care of temperature compensation. The output of the DC bridge was then fed into an amplifier and into the vertical deflection plates of the oscilloscope. With this circuit a straight horizontal line is obtained on the oscilloscope screen when the output of the bridge is zero. Any change in the voltage output of the bridge circuit, therefore, causes a change in the vertical deflection of the oscilloscope. Hence an impact pressure, acting on the beam, unbalances the bridge and causes a vertical deflection of the oscilloscope beam.

The contactor gage also consisted of a cantilever beam sensitive only to the engine impact pressures. The gage was so constructed that when the test beam was deflected a certain distance an electric circuit was completed. The signal from the deflection of the beam was then displayed on a cathode-ray oscilloscope. In this manner, when the electric circuit is completed the oscilloscope trace is deflected vertically. Beams of various thicknesses can be used in the holder to vary the sensitivity.

Test Apparatus and Preliminary Studies

A single cylinder CFR engine with 3½-in. bore and 4½-in. stroke driven by an induction-type dynamometer was used in these experiments. With the special test equipment provided for the engine it is possible to vary most of the engine parameters to obtain the desired test conditions.

The most desirable method of studying knock is obviously through experiments with an engine operating under knocking conditions. Unfortunately, the flame front in the engine can cause these experiments to become extremely complex. In the absence of the flame front in a motored engine, however, the entire charge in the cylinder can be subjected to the same physical conditions as the end-gas in a fired engine. With elimination of these difficulties, therefore, the motored engine provides an excellent experimental tool for studies of shock and detonation waves.

To obtain the desired natural frequency of the cantilever beam it was necessary to determine the

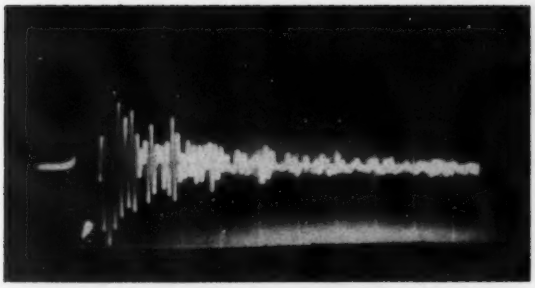

FIG. 3. OSCILLOGRAM SHOWING RATE OF PRESSURE CHANGE FOR NORMAL HEPTANE

Note detonation waves.

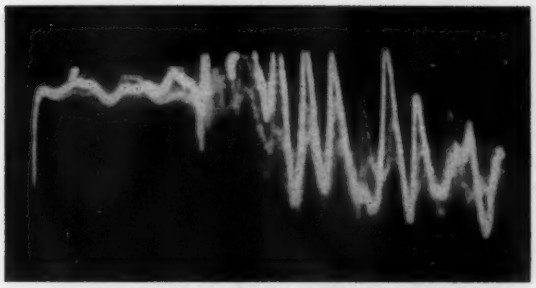

FIG. 4. OSCILLOGRAM SHOWING VARIATION OF IMPACT PRESSURE IN A KNOCKING ENGINE

frequency of the shock and detonation waves. A magnetostrictive indicator, measuring the rate of change of pressure, was installed in the engine for this purpose. It responds to the change of pressure of the engine by the deflection of its exposed metal diaphragm. The resulting electrical signal was then fed into the vertical deflection plate of a cathode-ray oscilloscope, and thus a diagram of the rate of change of pressure (dp/dt) against time was displayed on the oscilloscope screen. The internal sweep of the oscilloscope was used to lock the diagram on the screen.

In the motoring tests, at low compression ratios, a simple compression diagram (Fig. 1) showing the rate of change of pressure against time was obtained. An increase in engine compression ratio produced cool flame reactions which generated shock waves. The presence of the shock waves is quite evident in Fig. 2 where the several pressure waves of the shock are followed by a large number of pressure fluctuations of sevehal times greater magnitude. These latter pressure fluctuations, shown more clearly in Fig. 3, are assumed to be the detonation wave.

These magnetostrictive indicator oscillograms provided a measure of the frequency of the shock and detonation waves whose impact pressure was to be measured by the impact pressure gages.

Impact Pressure Experiments and Results

After the static loading of the impact pressure gage showed the anticipated sensitivity required for measurements of the impact pressures, the gage was then installed in the engine and was tested to determine its response to the engine static pressure. The engine was motored at 1400 rpm at a compression ratio of 9 to 1. A straight horizontal line indicated the lack of the test beam response to the engine static pressure.

To observe the effect of the detonation wave on the impact pressure gage, the engine was motored and allowed to undergo several cycles of compression ignition. The occurrence of knock completely altered the oscilloscope pattern to a number of large vertical waves. These waves, shown in Fig. 4, indicate the presence of the directional impact pressures in the knocking engine.

Conclusions

The data obtained by the impact pressure gage definitely show the presence of the impact pressures in a knocking engine and strongly support the data obtained by the magnetostrictive indicator. The experimental results of the foregoing studies, therefore, show that the cool flame reactions are capable of generating shock waves which then may lead to detonation waves and cause engine knock.

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HYPERSONIC FLOW ABOUT OGIVES

(Continued from page 12)

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The Application of Transistors to a Transmission Line Relay

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For some time the idea of using electronic devices to replace electromechanical relays for power-system application has been an appealing prospect. The negligible energy requirements for controlling the vacuum tube, as contrasted with the energy required to actuate electromechanical devices, offer an immediate advantage by minimizing load on the system's instrument transformers. Other advantages, which seem likely to be realized but not without a period of development, are (1) new principles of relaying with possible higher speeds and/or greater selectivity, (2) lower first cost, (3) lower maintenance costs through the elimination of moving parts with their associated bearings and contacts.

In spite of their possible advantages, electronic relays have not been widely accepted, the only noteworthy exception being the carrier-current type of relay. Among many reasons which may account for the lack of acceptance of electronic relays, the following are listed:

1) Lack of reliability of the vacuum tube itself
2) D-c power requirements, particularly for the heater circuits which must be continuously energized in order to be ready for service instantly
3) Deterioration of the tubes with prolonged inactivity
4) Lack of designs of electronic relays having any real performance advantage

In recent years junction transistors have become available in ratings suitable for power-system control application. The transistor requires no heater power and gives promise of a new order of reliability. All the potential advantages of the vacuum tube seem to be realized without its disadvantages. In addition, the transistor is available in the complementary PNP and NPN types, thus allowing simplifications of circuitry not possible with the vacuum tube. It must also be noted that, in addition to the transistor, a host of new semiconductor devices are now available, such as zener diodes and controlled rectifiers, with considerable potential for use in power-system relaying.

At the University of Washington work has been proceeding for the past five years on the development of transistorized control devices for power-system application. Attention has focused in particular on two devices: a transistor distance relay, and a transistorized automatic oscillograph starting unit. Prototype models of these devices have been installed in substations in the Northwest to provide operating experience, and results thus far appear promising. The transistor distance relay is described on these pages.

In discussing electronic relays one misconception must be clarified at the outset. It is often expected that electronic relays, because they eliminate the inertia of mechanical parts, inherently allow much higher operating speeds. This is not necessarily so in the present state of the art where high-speed electromechanical relays are operating in times of less than one cycle (on a 60-cycle basis). A distance relay, for example, operates on a principle of impedance measurement, and the concept of impedance as a complex ratio between sinusoidal quantities is essentially a steady-state concept. Until a half-cycle or so has passed by, the eventual trend (and therefore the steady-state impedance and distance measurement) is not well established. Merely to use electronic devices to construct a relay operating on the impedance principle does not in itself result in higher speeds. We must look to some of the other points listed above to realize some of the advantages of electronic relays.

Transistor Distance Relay

It has long been known that electronic equivalents may be built for the common types of electromechanical relays. The distance relay is a good example. A vacuum-tube version of such a relay was described by the author in 1954.[1] Laboratory tests indicated many desirable features of performance, but simultaneously with the development of this model suitable transistors began to be available, and plans for a prototype for field testing were dropped in favor of a transistor version.

A general functional layout of the transistor system is illustrated in block diagram form in Fig. 1. The a-c relaying quantities derived from the instrument transformers form the input to the system at the left. By means of a transistor gating circuit, current is allowed to flow in the collector of the transistor as a pulse of time duration determined almost entirely by the relative phase angles of the a-c input voltages and almost entirely independent of the magnitude of these voltages. The phase discriminator operates to produce a tripping pulse whenever the gate passes current for longer than a predetermined length of time,

and finally a transistor flip-flop circuit is triggered by this tripping pulse to operate a small electromagnetic relay, tripping the circuit breaker. The details of each of the functional blocks follow.

A-C Circuitry

The basic operating principle of the relay involves the comparison of the phase of two a-c voltages derived as shown in Fig. 2. Voltage $\boldsymbol{E}_1$ is proportional to the line voltage* and voltage $\boldsymbol{E}_0$ is derived from the line current by passing the current transformer output through an impedance, $\boldsymbol{Z}_0 = R_0 + j\omega L_0 = Z_0 \angle \zeta$; thus $\boldsymbol{E}_0 = \boldsymbol{I}(R_0 + j\omega L_0)$. The voltage $\boldsymbol{E}_0$ is then combined with $\boldsymbol{E}_1$ to form the net voltage, $(\boldsymbol{E}_0 - \boldsymbol{E}_1)$. The phases of voltages $\boldsymbol{E}_1$ and $(\boldsymbol{E}_0 - \boldsymbol{E}_1)$ are compared by the transistor gating circuit, the criterion for tripping being that the angle of overlap (the angle while the voltages are simultaneously positive or simultaneously negative) shall be greater than some particular value, ϕ_0.

The performance of a distance relay is ordinarily described in terms of the complex plane of impedance, usually called the R-X plane, where the operation of the relay is described in terms of its behavior for various values of the complex ratio, $\boldsymbol{E}_1/\boldsymbol{I}$. The significance of the operating criterion may be developed by starting with reference to the phasor diagram of Fig. 3 (a). The voltage phasor, $\boldsymbol{E}_1$, is drawn horizontally as the reference. For a particular value of the current, $\boldsymbol{I}$, the voltage $\boldsymbol{E}_0$ will lead $\boldsymbol{I}$ by the angle, ζ, and be directly proportional to $\boldsymbol{I}$ in magnitude, according to the relation $\boldsymbol{E}_0 = \boldsymbol{I}\boldsymbol{Z}_0$. The voltage $(\boldsymbol{E}_0 - \boldsymbol{E}_1)$ is the phasor connecting the tip of $\boldsymbol{E}_1$ and $\boldsymbol{E}_0$. The angle of overlap of the voltages $\boldsymbol{E}_1$ and $(\boldsymbol{E}_0 - \boldsymbol{E}_1)$ is shown as ϕ. If 90° is taken as the critical angle of overlap beyond which tripping is allowed, then it is evident that the relay will operate whenever the tip of $\boldsymbol{E}_0$ lies to the right of the line AA′. Now a simple geometrical construction will show that when the tip of $\boldsymbol{E}_0$ lies to the right of line AA′, then the $\boldsymbol{I}$ phasor tip lies outside the line BB′ which lies at an angle, ζ, with respect to AA′ and a distance $\mathrm{OP} = \boldsymbol{E}_1/\boldsymbol{Z}_0$ from the origin. If the phasors of Fig. 3 (a) are now divided by $\boldsymbol{E}_1$, the quotient $\boldsymbol{I}/\boldsymbol{E}_1$ is the admittance of the line as "seen" by the relay. The line BB′ in the admittance or G-B plane becomes the locus determining relay operation. When the apparent admittance, $\boldsymbol{I}/\boldsymbol{E}_1$, lies beyond this line, the relay trips. This type of operation is called a "mho" characteristic and is available in electromechanical types. The locus of operation is easily located by noting that the line OP′ is the complex number $\boldsymbol{Y}_0 = 1/\boldsymbol{Z}_0$, and the locus of operation is the perpendicular to this line.

Since the relay engineer is more accustomed to thinking in terms of the impedance or R-X plane, the locus of Fig. 3 (b) may be mapped onto this plane by means of the simple functional transformation, $\boldsymbol{Z} = 1/\boldsymbol{Y}$. From complex variable theory we know that this simple function maps circles from one plane into circles on another, and the straight line is included in the family of circles. Figure 4 (a) shows the resultant locus in the R-X plane, a circle through the origin with diameter determined by the complex number, $\boldsymbol{Z}_0 = Z_0 \angle \zeta$. When the apparent impedance

*For simplicity, the operation is described in terms of a single phase example.

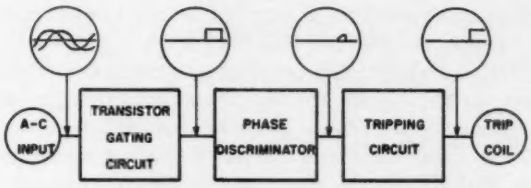

FIG. 1. FUNCTIONAL BLOCK DIAGRAM OF TRANSISTORIZED DISTANCE RELAY

Symbolic wave forms are illustrated for a fault within the reach of the relay.

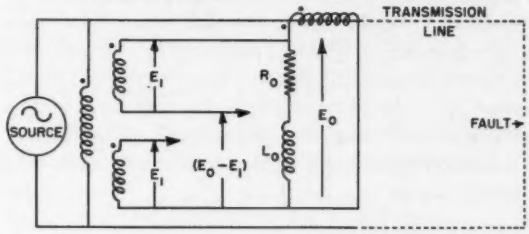

FIG. 2. A-C CIRCUITRY OF THE RELAY

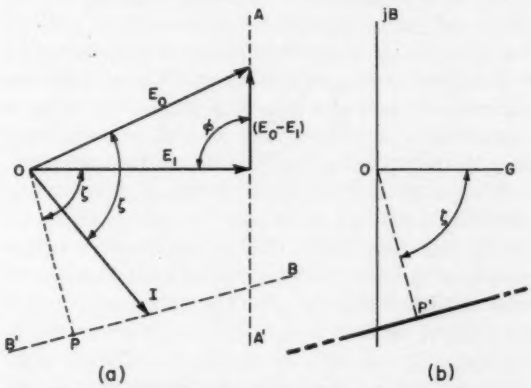

FIG. 3. ILLUSTRATION OF THE THEORY OF RELAY OPERATION IN TERMS OF (a) VOLTAGE OF CURRENT PHASORS, (b) THE ADMITTANCE PLANE

$\boldsymbol{E}_1/\boldsymbol{I}$ appears within the circle, the angle of overlap is greater than 90° and the relay trips.

By a slightly more complicated graphical procedure it may be shown that if the critical angle of overlap for ϕ is taken as other than 90°, then the locus of operation is made up of two line segments in the admittance plane and of two circular arcs with $\boldsymbol{Z}_0$ as a chord in the impedance plane. An example is shown for $\phi_0 = 150°$ in Fig. 4 (b). A simple change of constants in the electronic circuitry permits selecting any desired angle for ϕ_0. This is an excellent example of the possibilities of electronic relays in realizing types of performance not available in electromechanical forms. The restricted area of coverage of the locus of Fig. 4 (b) is of considerable practical advantage in applications where heavy load currents or power swings may cause false relay operations.

Transistor Gating Circuit

Figure 5 illustrates a simplified diagram of the transistor gating circuit used to produce a pulse in the collector circuit of time duration determined by the angle of overlap of the input voltages which are shown as $\boldsymbol{E}_1$ and $(\boldsymbol{E}_0 - \boldsymbol{E}_1)$. The angle of overlap is marked as ϕ on the diagram. It will be noted from the diagram that if the a-c quantities were not present a steady d-c current would flow in the collector circuit as determined by the current injected into the base. This is a grounded-emitter circuit using PNP junction transistors, and sufficient base current is injected that the collector current is determined almost entirely by the collector source voltage, V_{cc}, and load resistance, R_c. The a-c voltages are rectified by small germanium diodes and applied to the base with such polarity that if either voltage is even very slightly positive the transistor collector current is cut off. During the angle of overlap, ϕ, while both a-c voltages are negative, the transistor conducts through its load resistor with a current of constant magnitude. In the simplest possible form of the relay the collector current is passed through a small auxiliary relay so adjusted as to pick up whenever the angle ϕ exceeds a certain critical value. The phase-sensing device used in the experimental model was different, however, and will be described later.

Reference to the previous paper[1] will disclose the similarity between this circuit and that employing the vacuum tubes, but in practice the transistor and germanium diodes have different properties from the high-vacuum devices and provision must be made to

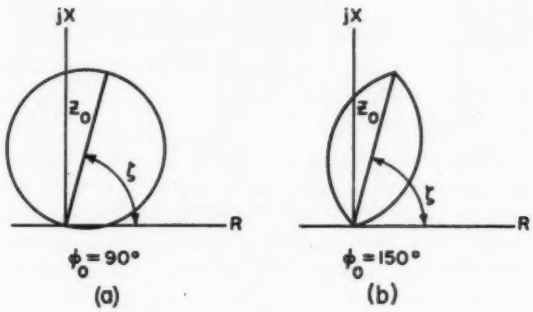

FIG. 4. ILLUSTRATION OF RELAY OPERATING LOCUS ON THE R-X PLANE

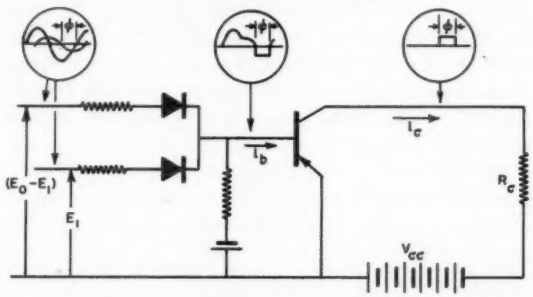

FIG. 5. PNP TRANSISTOR USED AS A GATING CIRCUIT TO COMPARE TWO VOLTAGES, E_1 AND $(E_0 - E_1)$

Note that the transistor conducts during the time in which both voltages are negative.

take account of these differences. The semiconductor devices are easily destroyed by excess inverse voltages and must be protected against them.*

Phase Discrimination

As mentioned before, the simplest means of phase discrimination and circuit breaker tripping is a small auxiliary relay in the collector circuit, adjusted to pick up whenever the conduction angle exceeds a certain desired value. While simple, this scheme of phase discrimination presents some difficulties. The number of auxiliary relays tends to become very great for a three-phase, three-zone distance relay installation. Further, the relay pickup angle is to some degree a function of the collector battery voltage, and the shape of the relay characteristic curve on the R-X plane may be modified by changing battery voltage even though the reach of the relay would not be affected. For these reasons, the relay described herein uses a different principle of phase discrimination, as illustrated in Fig. 6.

*The details of this protection are not shown, in the interest of simplicity.

As will be noted, the gating transistor collector circuit is modified by placing an inductance, L, in series with a potentiometer, R_1. This modification now causes the collector current to assume the well known exponential form of the R-L transient instead of the rectangular form illustrated in Fig. 5. The potentiometer picks up a voltage of the same wave form as the current. The diode, in conjunction with R_2, is biased in the nonconducting direction, but when the voltage from the potentiometer exceeds the back voltage of the battery a pulse of current flows through R_2. Since the height to which the exponential voltage wave rises is a function of its time duration and since the potentiometer is adjustable, the apparatus may be set to deliver a tripping pulse whenever the angle of overlap is greater than a specific amount. Thus the shape of the relay characteristic locus on the R-X plane is determined by the setting of the potentiometer.

This particular method of phase discrimination has the following advantages over the earlier method of using a relay in each collector circuit:

1. Only one triggering and tripping circuit is needed for all phases and zones of the relay.
2. Since both the collector current and the bucking voltage, which biases the diode, vary directly as the source voltage, the critical tripping angle, ϕ, is substantially independent of the source voltage.
3. If at any time the collector circuit is cut off by the action of the voltages applied to the base, the collector current drops to zero very rapidly. Thus the phase discriminator is "reset" almost immediately. This advantage is of importance when one considers the situation of faults following a heavy load current or faults having a large d-c transient offset.

Tripping Circuit

The last item in the block diagram of Fig. 1 requires little explanation since it is a rather conventional monostable flip-flop using two junction transistors. The circuit may be triggered by either positive or negative pulses coming from the phase-discrimination circuit of Fig. 6. The flip-flop then closes a small electromagnetic relay to trip the circuit breaker. The d-c control wiring of the breaker is conventional with seal-in relay, "a" switch, etc. In the prototype model of the relay, the flip-flop is arranged to reset in about six cycles in order to be ready for another tripping operation in the event of an automatic reclosing type of circuit-breaker duty cycle.

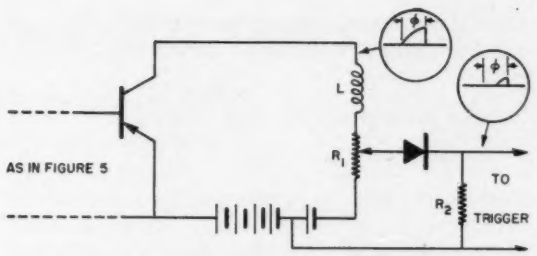

FIG. 6. PHASE-DISCRIMINATION MEANS EMPLOYED IN GATING TRANSISTOR COLLECTOR CIRCUIT

A pulse is transmitted to the trigger circuit whenever the gate conducts longer than a predetermined time.

Effects of Transients

Because of the clipping action of the transistor gate circuit, the relay is not greatly affected by transients of the type that amount to a high-frequency distortion of the wave form. Transients of the exponential offset type, however, pose a different problem since they may affect the time of the zeros of the relaying voltages, thus giving rise to a false indication of the angle of overlap, ϕ, and perhaps causing false tripping. Serious consideration has been given to the effects of transients of this type. A relay developed by Adamson[2] in England contemporaneously with the present device differs in electronic circuitry but uses the same basic operating principle. Adamson has made an ingenious provision to delay relay operation until exponential offsets have decayed; while this seems to be a successful approach to the problem, it suffers the disadvantage of slower speed operation. Exponential offsets may occur in either the voltage or the current, but in the Pacific Northwest voltage offsets are not often experienced, and the current offset is deemed the more important problem. This aspect has received considerable attention in the studies at the University of Washington.

In the University of Washington relay, the voltage, $\boldsymbol{E}_0$, is developed across a resistance and inductance in series*, as shown in Fig. 2. On an instantaneous basis we may write the equation,

$$e_0 = R_0 i + L_0 \frac{di}{dt}.$$

Let us now assume the current to be made up of a sinusoidal component and an exponential offset component:

$$i = I \sin(\omega t + \alpha) + I_t \varepsilon^{-t/T},$$

*The Adamson relay, by contrast, develops the voltage corresponding to $\boldsymbol{E}_0$ by means of a circuit amounting to a parallel inductance-resistance combination.

where I_t is the magnitude of the transient component and T is the time constant of the decay. It follows that

$$e_0 = R_0 I \sin(\omega t + \alpha) + \omega L_0 I \cos(\omega t + \alpha) + L_0 I_t (R_0/L_0 - 1/T)\varepsilon^{-t/T},$$

of which the first two terms are the a-c quantities determined by a steady-state or phasor analysis. The last term is an exponential offset and a potential trouble maker if its presence should cause the transistor gate to conduct too long on a fault which lies outside the relay locus. An analysis of the effects of the transient term is complicated because so many factors are involved; however, some of the more important effects will be discussed in the space available.

In the first place, it must be noted that if the ratio L_0/R_0 is chosen equal to T the offset term disappears. This is the usual case where the phase angle of Z_0 is the same as that of the line impedance which, in turn, largely determines T for faults of zero impedance near the far end of the protected zone.

If the fault has appreciable resistance, then T may not match L_0/R_0 and further consideration is necessary. In such a case compensating factors are at work. For very high fault resistances the rate of decay of the offset is so high that the offset has little effect on the relay. The sign and magnitude of I_t is determined by the previous current flowing and the time on the wave at which a fault occurs. In most cases the initial current may be considered to be zero or very low, with respect to fault currents. Fortunately, for the sign of I_t to be such as to cause false tripping, the fault must occur while $\boldsymbol{E}_1$ is blocking the transistor gate, and hence time is available for decay of the transient. The net effect of the various factors involved in offset transient behavior may be expressed in terms of the R-X locus by noting that the locus becomes a zone of possible operation as in Fig. 7, rather than a sharp line of demarcation between operation and no operation, as in Fig. 4. If a fault should appear in the shaded zone of Fig. 7, then tripping *may* occur, depending upon the random variables of previous load current and time on the wave of fault occurrence. The outer bound of the zone corresponds to zero probability of tripping, and the inner bound, or original relay locus, corresponds to unit probability of tripping. Sokkappa[3] has made a detailed analysis determining this zone of possible tripping based upon equal probability of fault occurrence at any point on the wave. It was found that for restricted loci on the R-X plane, ($\phi_0 > 90°$), the zone of possible misoperation is not sufficiently broad to endanger relay operation from the standpoint of overreach or tripping at distances beyond the normal zone of protection of the relay.

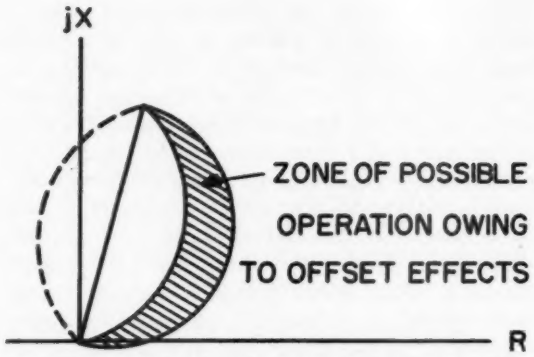

FIG. 7. DIAGRAM ILLUSTRATING THE EFFECT OF CURRENT OFFSET TRANSIENTS ON RELAY PERFORMANCE

Experimental evidence of the prototype model in the laboratory showed no tendency to overreach on literally thousands of test faults applied at random points on the wave with an artificial transmission line, so long as restricted loci on the R-X plane were used for the relay characteristic. For broad loci on the R-X plane ($\phi_0 < 90°$) definite trouble was experienced with overreach, attributable to offset transients. In the field installation the relay is set for a locus corresponding to $\phi_0 = 120°$, and no trouble with overreach has been experienced. Since the restricted loci are of principal interest in actual relay application, particularly in the Pacific Northwest where long lines are the common case, it is believed that any complications designed to reduce the effect of offset transients are neither necessary nor desirable.

It should be noted that the "bulginess" of the locus shown in Fig. 7 is of no consequence in the region below the extreme tip of the locus since maintaining a restricted area in the lower regions is of interest only from the viewpoint of prevention of false trips on load currents or power swings, cases which involve no offset transient.

Conclusion

The transistor distance relay described in these pages is one of many first steps into the area of electronic relaying for power systems. From the encouraging results thus far it is hoped that it may serve as a stimulus to further development in this promising area to the end of improved relaying on power systems.

(Continued on page 31)

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Pacific Coast ACS to Meet Here

THE PACIFIC COAST REGIONAL DIVISION of the American Ceramic Society will begin a three-day Seattle conference on October 15. Meetings will be held on the University Campus. Dr. E. E. Mueller, Associate Professor of Ceramic Engineerings, is general Chairman, and G. C. Carter, Ceramic Engineer of the Northwest Experiment Station (U.S. Bureau of Mines), is in charge of the program.

Special sessions will be held for these divisions: Aircraft Missiles, Nuclear Ceramics, Nuclear Refractories, Refractories and Structural Clay Products, Structural Clay Products, Glass, Glass and Refractories, Electronics, and Basic Science.

The following alumni of the University of Washington (all except one from the Department of Ceramic Engineering), are listed, as authors or co-authors of papers to be presented.

F. H. Simpson (Boeing Airplane Co.): "New Refractory Low, Zero, and Negative Expansion Ceramics."

Wm. Hanot (Mechanical Engineering) (Northwestern Glass Co., Seattle): "Batching Safeguards—The First Step Toward Homogeneous Glass."

L. Penberthy (Penberthy Instrument Co., Seattle): "Glass for Atomic Radiation Shielding Windows."

J. Persico, Larry Ryan, J. P. Sterry (all of Boeing): "Ceramic-Metal Brazing for Missile Structures."

J. P. Sterry, co-author of "Irdome Material Requirements."

Fen Bradley (Boeing), co-author: "Problems in Emissivity Measurements of Ceramic Materials."

Larry Ryan, J. P. Sterry: "Rain Erosion Testing of High Alumina Ceramic Materials."

Lavada Moudy (Atomics International, Canoga Park, California), co-author with Ceramic Engineering Professor J. I. Mueller (University of Washington): "Reaction Studies of the Uranium-Oxygen System."

Lt. C. E. Nordquist (USAF): "Present and Future Air Force Ceramic Material Requirements."

Daniel Auda (Boeing), co-author of "Rapid Particle Size Analysis of Ceramic Materials with an Electronic Counter."

Fen Bradley (Boeing): "Vitrification of Barium Titanate-Lead Stannate Ceramics."

At the luncheon on October 17, the National Institute of Ceramic Engineers will present Dr. R. Franklin Thompson, President of the College of Puget Sound, who will talk on "Out-Thinking Tomorrow."

About 250 ceramic engineers are expected to register for the conference.

Engineering Research Dividends

Recent theses submitted for advanced degrees from the College of Engineering, University of Washington, will regularly appear in abstract form in *The Trend*. Complete copies of these theses are available for reference at the University of Washington Library. Address inquiries to the Director of the Engineering Experiment Station, University of Washington, Seattle 5.

DREYER, G. H., "Decomposition of Supersaturated Alpha Phase in a Copper–4.9% Silicon Alloy," M.S. in Metallurgical Engineering, 1959.

This investigation was undertaken in order to clarify the decomposition behavior of supersaturated alpha phase in copper–silicon alloys at temperatures below 552° C.

Specimens of a copper–4.9% silicon alloy were homogenized in the alpha region at 760° C, quenched in water, and aged at temperatures of 525°, 450°, 375°, 325°, and 275° C. The decomposition of the supersaturated alpha during aging was followed by means of metallography and by measuring the changes in hardness and electrical resistivity.

The use of mechanical polishing before etching caused surface deformation which partially transformed the alpha phase, causing the formation of striations in the microstructure. These striations have been related by Hoffman, et al., to metastable kappa phase, whereas Barrett described the structures as severe stacking faults. Because of the lack of agreement, the striations are referred to as the "kappa prime" (κ') phase in this investigation. The use of chemical polishing just preceding etching removed the deformed surface and revealed the undeformed phase which was free of any striations.

The decomposition behavior of supersaturated alpha was very temperature-dependent. At 525°, 450°, and 375° C, large amounts of kappa prime formed prior to the appearance of the alpha phase. At 325° and 275° C where the amount of kappa prime formed prior to the occurrence of gamma was very small, the gamma phase appeared after a much longer time. This suggests that a temperature region below the kappa eutectoid exists where the kappa prime forms metastably during aging and represents a distinct state of alpha decomposition.

The gamma precipitation and growth occurred in three stages: formation of small particles, growth of the small particles into a pearlitic type of structure, and coagulation into large particles.

The formation of kappa prime phase from supersaturated alpha during aging increases the electrical resistivity and slightly increases the hardness of a 4.9% silicon alloy. The formation of gamma during aging decreases the electrical resistivity and increases the hardness until coalescence of gamma particles begins during the final stages of aging.

EDWARDS, R. P., "An Analytical Investigation of Unpowered Orbital Vehicles." M.S. in Aeronautical Engineering, 1959.

This thesis is the result of an analytical investigation to determine the theoretical surface temperatures and total heat that unpowered vehicles are subjected to while descending into the earth's atmosphere from an initially circular orbit. Both lifting and non-lifting vehicles were considered with various area-to-mass ratios.

Descent trajectories were determined by numerical integration of the equations of motion. The stagnation point heat transfer rates to the vehicles were calculated from an empirical expression and these results were integrated numerically to give the total heat transferred to a vehicle. An estimate of the relative importance of heat transferred to the vehicles by radiation from hot gases in the shock layer is given.

The final results indicate that for practical non-lifting re-entry vehicles ($C_D S/M < 10$), protection must be provided against high surface temperatures. It is also shown that the surface temperature of a body is lowered by incorporating lift, but more total heat energy would be transferred because of the longer duration of descent. It appears that the effect of heat transfer by radiation from the shock layer is negligible for the flight trajectories considered.

LONG, R. W., "The Role of the Triaxial Compression Test in Flexible Pavement Design." M. S. in Civil Engineering, 1958.

A number of rational methods have been proposed for flexible pavement design but none have been widely accepted as design tools, although they have contributed to knowledge and serve to guide our thinking in respect to the problem. A major difficulty is that when the theory of elasticity is applied to a material such as a soil, even though the approach may be rational, there is no assurance that the elastic coefficients are determinable, much less constant. Standard triaxial testing procedures, used to furnish the numerical values for the elastic coefficients, are

purely empirical unless the triaxial test duplicates field conditions. Presented here is a comparison between standard triaxial tests of a uniformly graded clean quartz sand and triaxial tests on the same material in which the lateral pressure is varied, as we might expect it to vary in a subgrade that is being subjected to a surface load.

Two triaxial test series were programmed according to this concept: one, in which the lateral pressure was constant throughout the test (standard procedure), and the other in which the lateral pressure was increased uniformly from a relatively low value to the maximum value just before the point of ultimate failure. The shear strength and stress-strain characteristics are presented for both types of test and the differences are illustrated. A comparison of the states of stress on the plane of ultimate failure for both test types is made for conditions throughout each test.

Since the testing program considers the lateral pressure to vary as a function of strain, Boussinesq's stress equations are used to compute the lateral pressures that might develop if they are a function of the applied vertical load. In order that the stresses may be approximated, the soil is assumed to approach the state of a semi-infinite isotropic elastic solid that has a Poisson's ratio of 3/8. Stress conditions are predicted on this basis and the results are compared with those of the triaxial testing program.

Although quantitive results were not obtained in this investigation, the indications are that stresses on the plane of ultimate failure are closer to the Coulomb failure envelope than is indicated by a standard triaxial test, particularly during the early stages of loading. This may explain road surface failures that occur at loads much lower than the design limit.

The results of this testing program also indicate that the standard triaxial tests, in which the lateral pressure is constant during the application of the load, do not, for granular materials, yield significant stress-strain relationships that can be rationally applied to flexible pavement design. When the triaxial test is programmed realistically, it will furnish accurate data for this use.

WILSON, M. E., "A Test Track Analysis for Gravel Equivalent of Asphalt Slabs." M.S. in Civil Engineering, 1958.

The purpose of this investigation was to make preliminary studies toward development of a design procedure for flexible pavements. The tests were conducted in a Highway Test Track which consists of a loading device and a tank containing the subgrade and pavement structure. Two additions to the test track were made to facilitate the testing program. A motor and gear box were installed to produce four speeds from 2.25 to 7.5 feet per second, and an axle strain indicator was developed to measure static wheel loads. Pressure cells were installed to determine the stress distribution due to loads applied to various base-course and asphalt-slab thicknesses. The experimental pressure distribution beneath the base course agreed with the Boussinesq equation; however, installation of the slabs spread the pressure over a wider area and reduced the stress directly beneath the load. The pressure studies led to the development of a gravel equivalent chart which shows the thickness of a base course which can be replaced by a given thickness of asphalt slab.

TUAN, YEN, "Heat Transfer in Natural-Convection Flow of Water." M.S. in Mechanical Engineering, 1959.

The experimental investigation reported here is the first part of a series of consecutive studies on the heat transfer in natural-convection flow of water over a vertical cylinder. Good solutions of the convection equations exist for the laminar flow case, but for turbulent flow no exact solution has been found. The only available solutions are semi-empirical equations, the validity of which depends upon the assumed velocity and temperature profiles. Furthermore, a great amount of experimental work is needed in the correlation of local film coefficients of heat transfer. This was the primary objective of the present experiment.

The test apparatus consisted of a copper cylinder with 12 separate electrically heated ceramic elements stacked inside. Thermocouples were installed to measure the local surface temperature of the copper cylinder and the bulk temperature of water. The experiment was first carried out in the laminar flow region, for which the test data and the established theory closely agreed. Then, the experiment was extended into the turbulent flow region. The evaluation of data showed good agreement with Eckerts' semi-empirical equation.

Johannes Kepler

(Continued from page 2)

recoil was spread over all parts of his body." He met "immense cold and inhibited respiration." During the first part of the journey, Kepler argued, "the body . . . no doubt escapes the magnetic force of the earth and enters that of the moon." The traveler is "then set free . . . for, as the magnetic forces of the earth and moon both attract the body and hold it suspended, the effect is as if neither of them were attracting it."

Free fall, a hundred years before Newton!

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OUTSIDE U. S. A.

Highlights from Our Foreign Exchange Publications

ON THE FLOTATION CHARACTERISTICS OF SPHALERITE IN RELATION TO ITS CHEMICAL COMPOSITION. Heikichi Saito, et al. *Bull. Sci. Engg. Res. Lab.*, Waseda University, Dec. 1958. Japanese.

The writers investigated thoroughly the flotation characteristics of sphalerite with various Fe content, along with its mineralogical properties.

The main results were as follows:

I The main mineralogical studies conducted in the research were: measurement of magnetic susceptibility, X-ray study, and spectral analysis.

X-ray study:

a) Employing the X-ray diffractometer, the lattice constant of sphalerite increases with the increase of Fe content. This is because in a sphalerite crystal the mode of bond increases the ionic nature with the increase of Fe content.

b) In the X-ray diagrams of the specimen showing much content of Fe, other Fe minerals were not recognized. Consequently, it is considered that in this specimen most of the Fe exists in the form of (Zn, Fe)S solid solution.

II Flotation characteristics

a) The natural floatability of sphalerite decreases with the increase of lattice constant and Fe content. This must be related to I-a mentioned above.

b) The recovery curves with various pH potassium ethyl xanthate solutions showed that each sphalerite specimen shows the maximum recovery at about 5 in pH value. On the further acid side, recovery decreases slowly, and on the alkaline side it decreases rapidly.

c) Recovery curves of the specimen, previously activated by copper sulphate, with various pH potassium ethyl xanthate solutions, showed that, compared with (b), the order of floatability of each specimen reverses, and an excellent recovery is shown on the alkaline side.

ON THE THEORY OF THE ELECTRON WAVE TUBE* WITH CROSS SECTION. P. Mattila. *Acta Polytech. Scand.* 1958. English.

The purpose of this paper is to derive the theory of the electron wave tube of elliptic cross section. The theory is based on small signal theory, equivalent to a simplification of the equations relating to the electron flow by neglecting quantities which become small when the signal is small. Furthermore, the magnetic field acting longitudinally in the tube is assumed to be of such magnitude that one is justified in neglecting the transversal motion of the electrons, the focusing forces of the field attaining adequate magnitude to prevent this kind of motion.

In electron wave tubes amplification is obtained in the electron flow, in which two or more electron streams of different velocities are mixed. If the densities of charge of the streams are sufficiently high, interaction occurs between the streams, making possible an amplification of the modulating wave in the velocity-modulated flow. It should be noted that the amplification occurs in the electron flow itself. In this way, a travelling wave with negative damping is produced. Modulation is suitably imparted to the electron flow by letting it pass, for instance, through a resonator excited by the input signal. The amplified output signal is similarly obtained by letting the electron flow act, for instance, upon a resonator tuned to the appropriate frequency. It is found that the electron wave tube is suitable for very short wave-lengths. The gain is essentially dependent on the distance between input point and output point. It is thus possible in principle to obtain very high gain by this method, if the length of the tube is sufficiently increased.

In the present paper the particular case is considered in which two electron streams with different velocities and D. C. densities travel in one and the same electron flow. The wave proceeds in the direction of movement of the electrons. The aim of this work was to calculate the gain in the elliptic wave tube described above and to compare the results to those which apply to the wave tube of circular cross section.

* An electron wave tube replaces the slow wave circuit of a traveling wave tube with a second electron beam. *Ed.*

DEEP FOUNDATIONS IN POOR SOILS. J. Kerisel, *Annal. Inst. Tech. Bat. Trav.*, Feb., 1958. French.

The construction of the Abidjan bridge has permitted an elaborate study of the problem of pile foundations in soils of the two-layer type having a thickness of poor soil on top of a more resistant layer.

After detailing the research carried out on cohesionless media under friction and explaining the phenomena of pressing back, construction and earth pressure, the author describes the Abidjan experiences where the subsoil consisted of a sand formation running down beneath 100 to 130 ft of mud.

A test was made on the river bank by loading to destruction a shaft of 4½ ft diameter identical to the column shafts of the piers. This shaft of 50-ft depth, fitted with 60 instruments measuring the shortening of the walls under the effect of the loads, permitted a determination of the stresses transmitted at each level. A jack suitably adapted gave a verification of the residual stress at the base.

After a description of this test the author deals with penetrometer tests.

EXPERIMENTAL DETERMINATION OF THE ELASTIC STABILITY OF ARCHES. Djordje Lazarevici. *Saopštenja*, Vol. 13, 1958, Serbo-Croatian.

The paper presents a newly constructed apparatus for the testing of lateral elastic stability of arches. This apparatus is designed for testing segmental arches with radial loading of unchangeable direction during deformation. With small accessory parts the apparatus could be arranged for testing arches of other axial outlines and also those with other conditions of support. The apparatus is planned for testing elastic stability and parabolical arches affected by actual vertical loading during deformation of an arch. Besides, it will also be possible to test conjugated systems, such as an arch-beam.

First tests were carried out with a mixture of gypsum and kieselguhr of a determined watergypsum factor. A material with low but constant mechanical characteristics was sought. The adopted composition practically satisfies these conditions. The parts remaining from each broken test block can be used for direct testing of the elastic modulus. The problem of elastic stability in practice is to attain full lateral rigidity by elastic supports of minimum resistance. The device has possibilities of controlling the behavior of the arches under the following conditions: without any inserted supporting points for lateral stability, with one inserted support in the middle and two others symmetrically placed one on either side of the middle one, and with three inserted supporting points.

ON SOME POSSIBILITIES OF CHANGING THE FLOW CHARACTERISTICS IN HYDRAULIC STRUCTURES BY BOUNDARY LAYER SUCTION. L. Escande, *Studii si Cercetari de Mecanica Aplicata.* IX-3, 1958. Rumanian.

Separation of streams, which may take place in various hydraulic structures, generally produces a decreasing of the discharge coefficient and a modification of the pressure distribution. This paper discusses some cases of such separations and presents effective solutions for avoiding the resulting negative effects. These solutions make use of boundary layer suction within the regions where the phenomenon occurs. Thus, in the case of spillways, the author recommends the use of collecting and evacuating suction slots. Such arrangements of the spillway crest essentially contribute to the improvement of flow conditions. Further on, the paper deals with the application of the same method in the case of a take-off situated at the point of deviation, and in other cases, e.g., flow through diffusers, flow with free surface through bends and flow around pillars.

Some examples the author gives show various possibilities of boundary layer suctions for avoiding the separation of streams.

The experimental research was carried out at the Toulouse and Banleve hydraulic laboratories.

TENSILE STRENGTH AND CRACKING IN NEAT CEMENT PASTES. M. A. Ilantzis. *Annales de l'Inst. Tech. Bat, Trav. Publ.,* Nov. 1958. French.

This article describes a test for determining the tensile strength of neat cement pastes. The test is performed by applying uniform pressure to the inside of a cement ring in order to break it. Numerous test results are given for two different cements and for two curing methods of the specimens in water and in an atmosphere with a relative humidity of 50 per cent. Analysis of these results shows that important stresses are caused by shrinkage.

A physical analysis of the cracking test was then made in the light of the findings of the tensile strength test. This analysis shows the practical impossibility of establishing a correlation between cracking time and the other characteristics of the material. It is nevertheless shown that cracking time, although a conventional characteristic, may be used as a general indication of the quality of a cement.

PHOTOELASTIC INVESTIGATION OF THE STATE OF STRESS IN GRAVITY DAMS WITH ORIFICES. Vlatko Brčič. *Saopštenja,* Vol. 12, 1958. Serbo-Croatian.

In designing gravity dams with orifices it is very important to know the stress concentration around critical places, such as orifices, cuts, etc. This paper covers the analysis of the stress in gravity dams with orifices of various sizes and positions. Three types of models with various positions of the orifices are described in this paper.

The problem is approached on the plane problem of the theory of elasticity. A triangular plate is observed, loaded in its plane by hydrostatic pressure on one side, and firmly fitted in the base. The boundary conditions are given both for the stress and deformations. The influence of its own height was not taken into consideration.

The problem is solved by the method of photoelasticity with application of the graphic integration and numeric computation of the Laplace equation for the main stresses; diagrams are given for the magnitude and directions of the main stresses with all three observed models. Pictures of the device by which hydrostatic loading was done are shown in the paper, as well as pictures of isochromes and isoclines for each model. All the testing was carried out in the Laboratory for Photoelasticity in the Institute for Hydraulic Engineering, under the direction of Ing. Jaroslav Cerni.

NEW PROJECTS

Project No. 259. A Theoretical and Experimental Analysis of the Thermocouple as a Means of Direct Conversion of Nuclear Energy into Electrical Energy. Supervisor: D. E. McFeron, Professor of Mechanical Engineering; Research Assistant: R. L. Straley.

Project No. 260. Foil Strain Gages in Vibration Damping. Supervisor: E. E. Day, Professor of Mechanical Engineering; Research Assistant: R. D. Miller.

Project No. 261. Truck Fuel Survey. Supervisor: R. B. Sawhill, Assistant Professor of Civil Engineering; Research Assistant: D. L. Crumbley.

Project No. 262. Investigation of the Effect of Fuel Manufacturing Process on Piston Ring Wear in an I.C. Engine. Supervisor: H. T. Meador, Assistant Professor of Mechanical Engineering; Research Assistant: L. M. Forsgren.

Project No. 263. A Nuclear Reactor Shield Design Study. Supervisor: A. L. Babb, Associate Professor of Chemical Engineering; Research Assistant: D. C. Kolesar.

Project No. 264. Reactor Kinetics of the Uranium-Oxygen System. Supervisor: J. I. Mueller, Professor of Ceramic Engineering; Research Assistant: Lavada A. Moudy.

Project No. 265. An Investigation of Non-Linear Dielectric Properties of Ferroelectrics. Supervisor: J. L. Bjorkstram, Assistant Professor of Electrical Engineering; Research Assistant: R. J. Mayer.

Project No. 266. Studies of 50-50 Nickel-Manganese Alloys. Supervisor: E. C. Roberts, Professor of Metallurgical Engineering; Research Assistant: J. R. Wolfe.

Project No. 267. Acoustic Measurement of Wind Velocity. Supervisor: W. R. Hill, Professor of Electrical Engineering; Research Assistant: R. L. Dhar.

Project No. 268. Phase Transformations in Zirconium-Vanadium Alloys. Supervisor: D. H. Polonis, Associate Professor of Metallurgical Engineering; Research Assistant: H. Okimura.

Project No. 269. Measurement of Acoustic Velocity in Very Wet Steam. Supervisor: J. C. Firey, Associate Professor of Mechanical Engineering; Research Assistant: R. E. Collingham.

Project No. 270. The Study of Boiling Heat Transfer Under Artificial Gravitational Fields. Supervisor: C. P. Costello, Assistant Professor of Mechanical Engineering; Research Assistant: W. E. Tuthill.

The U. of W. Center for Graduate Study at Hanford

THE GENERAL ELECTRIC COMPANY, under prime contract with the Atomic Energy Commission, operates the facility known as the Hanford Works in Eastern Washington. This World War II development provides employment for about 8,000 persons in the Tri-City (Richland-Kennewick-Pasco) area. To meet the educational needs of this group, a school was established in 1946 known as the General Electric School of Nuclear Engineering. The University of Idaho, Oregon State College, Washington State University, and the University of Washington recognized this school and allowed transfer of earned credits.

This school was transferred to the administration of the University of Washington as of July 1, 1958, and has since been operated as the University of Washington Center for Graduate Study at Hanford. However, cooperation among the four institutions of higher learning mentioned above is continuing, so that the universities now allow, under certain conditions, application of credits earned at the Center for Graduate Study in degree programs on their respective campuses. The University of Idaho plans to complete in 1960 a gradual withdrawal from the program and is not accepting new students.

When the administration of the Center was undertaken by the University in 1958, it became a part of the Graduate School, now headed by Dean Joseph L. McCarthy. Dr. Kermit B. Bengtson, who had completed his post-graduate studies in the Department of Chemical Engineering, was appointed Director.

The Graduate Study Program includes courses applicable to advanced degrees in six divisions of engineering: chemical, civil, electrical, mechanical, metallurgical, and nuclear, in addition to chemistry, mathematics, and physics. The 32 graduate faculty members have been trained in universities and technological institutes in many parts of the country and were selected from highly competent local employees with advanced degrees.

A Master of Business Administration degree program offered to Richland students is being staffed largely by regular university faculty members who commute to and from the Seattle campus. Lower-Division Extension courses are also given in subjects not offered by the Columbia Basin Junior College, such as Business Administration, Engineering, and Far Eastern and Slavic Languages and Literature, to help meet the needs of students unqualified as yet to register in the Graduate School, and/or to supplement the graduate departmental requirements. Four University faculty members conduct these classes.

Last year five students obtained Master of Science degrees in affiliation with the University of Idaho and one student obtained a Master of Science degree in affiliation with Washington State University. One student completed work for his Ph.D. degree at Oregon State College after having taken a considerable portion of his course work at the Center in Richland.

This year it is anticipated that approximately six students will obtain M.S. degrees in affiliation with the University of Idaho and one additional student will complete work for his Ph.D. degree at Oregon State College after having taken a considerable amount of work at the Center.

Last year on the semester system the fall enrollment consisted of 277 students and the spring enrollment consisted of 176 students. This year, on the quarter basis, autumn quarter enrollment is 276 students.

Approximately 500 different individuals have been enrolled in courses since the University took over administration of the Center on July 1, 1958. A good many of these individuals are, of course, still enrolled at the present time. About 450 of the 500 students were or are enrolled in graduate courses with the balance being enrolled in non-credit, lower division, or extension courses. At the present time all of the students are enrolled either in courses which carry graduate credit or which are preparing them for courses which do carry graduate credit, but about 10 per cent of the students are taking these courses primarily for their own information and do not expect to apply the credit obtained toward a graduate degree. Nearly all individuals in this latter category already hold advanced degrees.

Nearly everyone who has taken courses at the Center has been connected either directly or indirectly with the Hanford Atomic Products Operation, although two housewives, four high school students, and one school teacher enrolled in the beginning Russian course offered last spring term. Currently enrolled in various technical courses are one Army Corps of Engineers employee, one employee of a contractor working on the Ice Harbor Dam, one man employed by the local public utility district, and

one man employed by the Western Electric Company. One housewife is currently enrolled in the Master of Business Administration degree program.

Eighty-seven per cent of all new graduate students enrolling since September, 1958, have elected to affiliate with the University of Washington. As of June, 1959, there were enrolled as graduate students in affiliation with the University of Washington 5 chemists, 14 chemical engineers, one civil engineer, 11 electrical engineers, 4 mechanical engineers, 2 metallurgical engineers, 21 nuclear engineers, 11 physicists, 18 unclassified fifth-year students, and 3 undergraduate students. This figure comprised only 55 per cent of the graduate students who were enrolled at the Center, the others being enrolled in affiliation with the University of Idaho, Oregon State College or Washington State University. Most of the graduate students not affiliated with the University of Washington were affiliated with the University of Idaho and the percentage of affiliation with the various schools will naturally change somewhat as the University of Idaho students complete their programs prior to the University of Idaho withdrawing from Center affiliation in June, 1960.

The Center has classroom and office space in a building located in downtown Richland. Students who need research facilities for their course work use facilities owned by the Atomic Energy Commission and managed by the General Electric Company. A few students are currently doing thesis research under this arrangement and it is expected that the use of General Electric Company and Atomic Energy Commission facilities for research and for laboratory course work will increase considerably in the future as the University, the AEC, and the General Electric Company work more closely together in the Richland program. Facilities and equipment which have been used in the past include a laboratory and electronic apparatus where experimental work for the Transistor Circuit Engineering course was carried out, X-ray crystallography equipment, and various other facilities used for thesis research on an individual basis. During the spring quarter a subcritical assembly constructed especially for teaching purposes is expected to be available for use in a nuclear engineering laboratory course, along with other already existing test reactor facilities.

According to Director Bengtson, the attitude and study habits of the graduate students at Hanford vary as widely as those in any large group of graduate students, but most of the Hanford students are very dedicated. Nearly all of them are married and have families. They have been out in the business world and have learned the value of graduate training, so they take their graduate work very seriously.

Off-campus graduate training was virtually unknown in academic circles ten years ago. Today it is playing an ever increasing role in graduate instruction, and as modern civilization demands the concentration of large numbers of scientists and engineers in certain places to study technological problems of importance to the national welfare, its growth is likely to continue to spread. An off-campus graduate training program very similar to the University's program is operated by the University of New Mexico at the Los Alamos Scientific Laboratory. Other such programs of varying degrees of similarity are operated at other large laboratories all around the country where there are concentrations of scientific personnel.

APPLICATION OF TRANSISTORS TO A TRANSMISSION LINE RELAY

(Continued from page 20)

ACKNOWLEDGMENT

The author wishes to acknowledge the support and encouragement of Mr. A. W. Adams and others of the Branch of System Engineering, Bonneville Power Administration, in pursuing this study.

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Note: **With this issue of *The Trend in Engineering* and the completion of Volume 11, the editor is retiring. Her successor, Mr. H. Harold Kelley, who has been Asssociate Professor and Editor at the Ordnance Research Laboratory at Pennsylvania State University, will arrive in time to take over the January, 1960, issue. To all of our readers and to the numerous engineers, librarians, and professors, both here and abroad, whose letters have often produced pleasant interludes in the editorial round, our appreciation and good wishes!**

Isabel W. Hemenway

What About Women Engineers?

(Continued from page 1)

of modern marriage which includes such general aspects as the following:

a) The trend of the past ten years toward earlier marriages results in completing the period of child rearing at an earlier age.

b) Reduction of the time necessary for domestic duties and reduction of the number of working hours in industry have increasingly drawn married women into employment. Many established women engineers have even found it interesting and profitable to carry on part-time, free-lance, or "consulting" work from their homes, while their children were small.[5] By this means, also, they contrive to keep up-to-date and have less need for refresher courses advised for those who resume their profession after a lapse of ten years or more.

c) "The companionate, equalitarian family is replacing the patriarchal, authoritarian family," to an extent that "the married career woman is finding greater cultural acceptance."[2]

Whether or not these changes will ultimately be for the better cannot be predicted, but they have undoubtedly arrived and we must face them. While acceptance of the woman professional engineer may lag a little, it, too, is on the way.

The Basic Obstacle

The superficial prejudices outlined here as examples, will, for the most part, be overcome after a little more time and experience. But they, as well as others, are unfortunately based on concepts older than civilization. President DuBridge notes that "social custom requires little girls to play with dolls instead of electric trains."[1] Today, from her infancy, influences and pressures are brought to bear on the girl to learn and value only the ancient culturally approved role of the housewife and mother.[2] Many mothers (and fathers) do not even know what a modern engineer does. In a recent series of 16 interviews with men and women of many occupations who were asked to define an engineer, the writer was repeatedly told that "he runs a locomotive" or "is in charge of the school furnace." On being asked who was responsible for their electric appliances, 75% of the women gave the company trade name, "G.E.," "Westinghouse," etc., and had apparently no idea that individual engineers, or research teams of engineers, were responsible for the design. Teachers tend to "relax intellectual standards for girls" and mass media "extoll the glamor girl."[2] These ingrained social ideas often extend to the campus and prejudice administrators against encouraging women to enter the engineering profession.

A story is told of "one able and highly motivated woman who was originally refused admission to the engineering school of her home state, who . . . enrolled elsewhere, completed two years in one and returned—this time to be admitted. . . . Her work performance has been such that she has for some time headed the specifications staff in the Aircraft Division of the C.A.A.[3] There may be others, just as gifted, but more easily discouraged who would find fulfillment and satisfaction in engineering and science training, and who would personally contribute to the world's balance and welfare *even if they never performed a day's work as professional engineers.*

However, few women graduates in engineering fail to follow their profession for at least a time. The *University of Colorado Engineer* recently carried a survey of the 63 women engineering graduates from 1903 (the university's first graduating class, which included one woman engineer) to 1957. Forty-two of the 63 married; 30 of them married engineers; five were daughters of engineers. Only five did not work as engineers after graduation. Thirty-two were working or on leave of absence at the time of the report (March, 1958).[6]

Looking Ahead

If girls with aptitudes for science and mathematics are encouraged to enter the engineering profession and if professional taboos are gradually withdrawn, what will be the result?

Under the most promising circumstances only a relatively small addition to engineering "man-power" will probably be made. There is little likelihood of the profession suffering a female invasion. After more than a century of medical training for women, in 1950 only 6% of the country's practicing physicians were women; yet "healing the sick" is generally held to be "more womanly" than designing a highway or a new type of rotor. Still, even a comparatively small number of trained women engineers would form a valuable reserve nucleus in case of emergency. During World War II the splendid response of women to fill the gaps in industrial employment left by men called to the service was beyond all expectations, and "Rosie the Riveter" has become a legend. Such encouragement during the war years, reflected in the peak numbers of women graduates at Colorado (nine in 1947, seven in 1948, eight in 1949), shows a sensitive response to public opinion. Unfortunately, after 1947 the number of women registrants in engineering dropped abruptly, with the result that only two were graduated from the University of Colorado in 1952 and 1953, one in 1954, and two in 1955, 1956, and 1957.

But the most important effect of encouraging women to specialize in science and technology, would be on the women themselves, those who wish to become engineers, physicists, or mathematicians because their talents and aptitudes, their curiosity and imagination, lead them in that direction. Certainly, the first step must be taken by the colleges and universities, to indicate whole-hearted approval of women engineers and to encourage qualified registrants, as several progressive institutions have already done. Then, as one writer has suggested, in conducting such a program of action, professional engineering societies can exert their influence and prestige to increase the likelihood of its effectiveness.[2]

Finally, if your small daughter says that she prefers a toy dump truck or an electric train to a Betsy-Wetsy doll for Christmas, why not give it to her?

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